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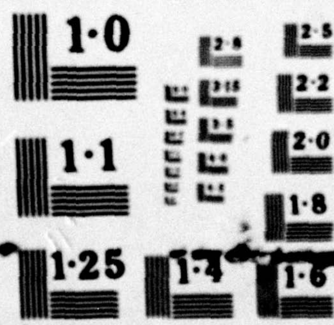

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A Multipurpose Expedient Paving System (MEPS) is being developed to enable more rapid construction of Expeditionary Airfields (EAF's) by Marine Corps forces engaged in an amphibious landing. Previous investigations demonstrated the potential of FOMAT – a structural sandwich composed of a 20-pcf rigid polyurethane foam core with fiberglass-reinforced polyester resin (FRP) facings. FOMAT met F-4 aircraft static load, tailhook

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impact, and engine exhaust blast requirements. The FY-77 research effort, covered by this report, focused on pavement concepts more amenable than FOMAT to field construction. Investigations were made on alternative concepts of (1) mechanically locking prefabricated bottom facings to the core and (2) eliminating the bottom facing while adding fiberglass reinforcement to the foam. FIBERMAT (FRP bonded to a layer of fiberglass-reinforced rigid polyurethane foam) is rated as the more viable concept. FIBERMAT has been subjected to a series of laboratory tests to define response to stress fatigue and environmental cycling. Finite element techniques are utilized to design FIBERMAT pavement sections for EAF traffic areas and varying soil strengths. Costs and benefits are projected, project technical risks are discussed, and major development milestones are outlined.

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CONTENTS

INTRODUCTION

Objective

The overall objective of the medium duty airfield pavement project is to develop the technology necessary for Marine and Navy engineer units to have an improved capability of expediently constructing an airfield pavement in an Amphibious Objective Area (AOA). The pavement is to be characterized by (1) adaptation to specific soil strengths and aircraft loads, (2) rapid field construction, (3) durability, and (4) minimal logistics burden. The current objective is to render an interim decision on the technical feasibility of such an airfield pavement. This report documents FY-77 exploratory development of the surfacing concept and discusses concept feasibility.

Background

A Marine Air/Ground Task Force (MAGTF) relies on the coordinated teamwork of ground troops and air support to successfully combat hostile forces within an AOA. Initially carrier-based, the air elements must be phased ashore at the earliest opportunity to release vital aircraft carriers for priority sea control missions. Marine Air Groups (MAG's) contain a mixture of conventional fixed-wing fighter/attack, Vertical and Short Takeoff and Landing (V/STOL), and rotary- and fixed-wing transport aircraft. Each aircraft type exhibits totally different field operating characteristics and landing gear ground loads from any other. Economy in airfield construction, reduction in logistic support, and an earlier initial operating capability (IOC) for tactical airfields may be achieved with an airfield pavement that enables design and construction specifically for the various MAG aircraft and for actual terrain conditions.

The conceptual pavement also must be compatible with all aspects of the Short Airfield for Tactical Support (SATS) concept of the Navy/Marine Corps. Within this concept, designs have been specified for Vertical Takeoff and Landing (VTOL) Forward Landing Sites, Vertical and Short Takeoff and Landing (V/STOL) Forward Operating Facilities, Short Airfields for Tactical Support (SATS), and Expeditionary Airfields (EAF's) (Ref 1). The SATS and EAF would support conventional fixed-wing fighter aircraft and must be designed for heavy static and dynamic gear loads requiring a medium duty pavement.* The V/STOL fields, in contrast, are not subject to either hard landing impact or dynamic loads induced by high-speed taxi; these fields sustain traffic from relatively lighter gear loads and thus require light duty surfacing.

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*A "medium duty" surfacing must withstand 1,000 coverages of a 25,000-pound wheel load at a tire pressure of 250 psi (Ref 2).

The military has extensively developed and tested families of prefabricated mattings for use on tactical airfields. Such mattings have performed adequately, although they have proven to have several disadvantages, including: difficulty of bomb damage repair, infiltration of water through joints with subsequent deterioration of subgrade support, and inefficiency of design. Because mattings are designed and fabricated for "worst use" soil and aircraft load conditions, inefficiency results when the mattings are utilized on stronger subgrades or under lighter aircraft loadings than originally specified.

As a result of the developmental effort of the expedient pavement concept a structural sandwich, FOMAT, has been fabricated and subjected to preliminary laboratory model studies, heat/blast tests, tail hook impact tests, and aircraft traffic tests (Ref 3).

OPERATIONAL REQUIREMENTS

Orderly development of the pavement concept and decisions concerning feasibility of the concept have resulted in a list of system requirements,* which have been subdivided into (1) required characteristics and (2) aircraft loading conditions for medium duty expedient pavement. The requirements were derived from review of the Army-approved Qualitative Material Requirement for Prefabricated Airfield Surfacings (Ref 2) and consideration of amphibious needs of the Marine Corps.

Required Characteristics

1. The pavement shall be capable of direct installation upon graded subgrades having California Bearing Ratio (CBR) values greater than 4.

2. The pavement shall be capable of being designed and field-constructed to specific soil conditions and aircraft loadings.

3. The pavement shall be capable of withstanding the medium duty aircraft loading conditions while having the following logistic factors:**

   (a) Basic materials should not weigh more than 8 psf and the coverage to shipping volume ratio for containerized mode should not be less than 4 sq ft/cu ft.

   (b) In-place material costs should be less than $6.00/sq ft of surfacing area.

   (c) Material emplacement, using equipment, should be at a rate of 10,000 sq ft/hr with an average 64-man crew.

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*These requirements are for guidance in the development of an expedient medium duty pavement and do not represent official Marine Corps doctrine.

**These factors are based on the "worst use" load conditions; stronger subgrades (CBR > 4) or lighter aircraft loadings will result in improved logistic and cost factors because of surfacing design.

4. Any toxic or hazardous components shall not have ratings (NAVMAT Instruction P5100) in excess of health (3); fire (2); and stability (3). The aggregate of any such components shall represent less than 3%, by volume, of the total surfacing materials. Health hazards to construction crews from such components shall be eliminated by use of (1) safety devices, such as protective clothing and mechanical filter respirators and (2) equipment or material design minimizing manual involvement.

5. Paving materials shall be capable of sufficient curing to permit service within 120 minutes of application during initial construction. Accelerated cure time of 30 minutes shall be required for materials used in repair work.

6. The pavement shall be emplaceable from 40° to 110°F with feasibility of emplacement at 20° to 40°F. Cured pavement shall be serviceable under seasonal temperature changes of 100°F and daily temperature gradients through the pavement depth of 75°F during service life at ambient temperatures ranging from -20° to 120°F.

7. The pavement shall provide effective braking with a coefficient of friction, μ, of 0.50 or greater during all ground operations and under wet conditions.

8. The pavement shall resist adverse effects resulting from exposure to POL* spillage, helicopter downwash, and vehicle wheel traffic.

9. Storage requirements have not been defined as yet.

10. The pavement shall possess a service life of not less than 6 months, with not more than 10% replacement of material due to failures and shall possess the durability to sustain 500 sorties of initial operations without failure.

11. The pavement shall withstand jet engine blast effects of 700°F for 10 seconds without damage or nonrecoverable loss of strength.

12. Cured pavement materials shall be self-extinguishing when ignited, and flames shall not propagate. Any structural damage from burning shall be readily repairable.

Aircraft Loading Conditions

The design aircraft for medium duty pavement shall be either the F-4, F-14, F-18, AV-8B, A-6, or KC-130, whichever provides the more stringent requirements for the loading conditions under consideration. The following loading conditions are to be considered; the pavement shall:

1. Withstand 1,000 coverages of an equivalent single wheel load (ESWL) computed for the maximum aircraft takeoff weight and the usual tire pressure and contact area of a main gear wheel, when constructed over a soil having a CBR of 4.

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*Petroleum, oil, lubricant.

2. Withstand static loads equivalent to dynamic taxi loads (takeoff and landing rollout) induced by roughness contours consisting of 1-cosine shaped undulations of constant wave length. Such undulations shall have all combinations of heights and lengths specified in Figure 1. The shape of the undulations in the lateral direction shall be held constant.

3. Withstand a static load equivalent to a dynamic impact load resulting from a landing at a sink rate, V_v, such that the probability of landing at a greater sink rate is ≤ 0.10. The design aircraft shall be assumed as landing in a taildown attitude with zero degrees roll.

4. Withstand static horizontal shear forces resulting from one-half the maximum landing weight of the aircraft distributed over the combined normal tire contact areas of all main gear wheels.

5. Withstand two tailhook impacts of 80 knots at equivalent 18-fps sink speed at the same location without structural failure.

6. Withstand 20 roll-over loadings on a 1-in.-diam arresting cable with a wheel load, nominal tire contact area, and tire inflation pressure for one main gear wheel of the aircraft at maximum takeoff weight.

CONCEPT DEVELOPMENT

Design Factors

The major factors to be considered in design of conventional airfield pavements include aircraft type, traffic volume, and mode of operation. Under aircraft type are subfactors of gear configuration, wheel loads, and tire pressures. Similarly, traffic volume is characterized by degree of aircraft wander transverse to the longitudinal pavement centerline, the movement of given aircraft within a specific time period, and the longitudinal variation of aircraft load. The mode of operation accounts for the aircraft speed and dynamic effects (such as turning, braking, landing impact and rollout, and dynamic taxi effects).

Such factors for conventional pavements are not considered in the design of expedient airfields surfaced with prefabricated mattings. With this type of airfield, a parking apron trafficked by slow-moving aircraft is surfaced with the identical matting section as a runway subjected to dynamic loads resulting from roughness contours and aircraft taxi at high speeds (on the order of 150 mph). To be functional over a wide range of design factors, expedient mattings have been designed for "worst case" soil strengths (approximately CBR 4 to 6) and maximum aircraft loads. Economic and logistic savings could thus be realized with an expedient paving system that could be designed for specific traffic areas and subgrade strengths.

Airfield Traffic Areas

The layout of a typical EAF was analyzed, and four traffic areas were identified (Figure 2).

Type A: A traffic area within the parking apron for slow-moving aircraft having ESWL's < 30,000 pounds and with tire pressures < 350 psi. The Type A area is suitable for F-18, F-14, and A-6 aircraft.

Type B: A portion of the parking apron with only traffic from slow-moving aircraft having equivalent single wheel loads less than 15,000 pounds and with tire pressures less than 200 psi. The Type B traffic area is capable of handling A-4, AV-8, and C130 aircraft.* The Type B area is suitable for surfacing with the Advanced Multipurpose Surfacing System (AMSS).

Type C: Those portions of the runway subjected to the dynamic loads associated with high-speed taxi of aircraft during takeoff and landing rollout. Although runway traffic is subjected to lateral wander, the greatest traffic concentration occurs at the runway center. Reduced traffic along runway edges permits thinner sections along edges with respect to sections at the runway center. The lateral traffic distribution width** for the typical EAF runway is illustrated in Figure 3.

Type D: This area extends 1,000 feet to either side of the two primary arresting gears and is that area of the runway subject to high dynamic landing impact, tailhook impact, and abrasion from the arresting pendant.

BONDING INVESTIGATION

FOMAT, a structural sandwich composed of rigid polyurethane foam between outer-facings of fiberglass-reinforced polyester (FRP), (Figure 4) has been investigated as an expedient pavement concept. Laboratory-fabricated FOMAT successfully met many of the criteria for medium duty pavement; however, field-constructed FOMAT test sections failed prematurely when subjected to medium duty (25,000-pound wheel load, 250-psi tire pressure) traffic (Ref 3). The cause of failure was identified as deficiency in bonding between the bottom FRP facing and the foam core. The major emphasis of the FY-77 effort, therefore, has been development of a bonding method adaptable to field construction techniques. In the course of the bonding investigation, several core materials were studied, and concepts were evaluated that would either mechanically bond the lower facing or that would eliminate the lower facing requirement.

*The C-130, which has an ESWL of 44,400 pounds, is included because of its relatively low tire pressure of 95 psi.

**Width within which the centerlines of all aircraft tend to remain 75% of the time in traveling along a pavement (Ref 5).

Core Materials

Syntactic Foam. Equipment available within the resin spray-up industry can produce a type of syntactic foam by spraying glass microspheres and polyester resin (Ref 6 and 7) in converging patterns.

Syntactic foam evidences good mechanical strength properties and produces excellent bonding between facings and core, since both are polyester-based. The major disadvantage with syntactic foam is the lack of expansion associated with the construction of the core (in contrast to polyurethane foam, which expands to four times the original volume). Thus, even though thinner cores are possible, a greater shipping logistic burden is encountered.

Foamed Polyester Resin. An Aliphatic AZO foaming agent, which produces a structural foam when added to polyester resin, is under development by private industry (Ref 8). This foam has excellent potential for military surfacing applications. Beneficial qualities include:

- Compatibility with glass fiber reinforcement to produce excellent mechanical properties
- Component expansion during foaming
- Even rise of foam
- High resistance to environmental degradation
- Compatibility with conventional resin spray-up equipment
- Varied foam density at the mixing head

The catalysis is triggered by the acidity of the polyester resin, which provides an additional benefit in that the foaming process is less sensitive to ambient temperature than polyurethane foam. Unfortunately, the foamed polyester resin process cannot be used as yet for military surfacing applications because of the high toxicity and instability of the foaming agent. The agent must be refrigerated below 0°F to prolong shelf life and becomes unstable at 115°F. Private industry is conducting research to improve the safety of the foaming agent.

Rigid Polyurethane Foam. Several different types and densities of rigid polyurethane foam were previously tested and evaluated as a surfacing core material. The optimum foam type was found to be a 20-pcf rigid polyurethane of the isocyanate family and was used extensively as a core material for FOMAT. The foam CPR-739, is manufactured by the CPR Division of the Upjohn Company. CPR-739 is a CO_2-blown foam, has a lower vapor pressure, and is less toxic than other polyurethane foams, which contain toluene diisocyanate or halocarbon-blowing agents (Ref 9). The mechanical properties of CPR-739 in 20- and 25-pcf densities are listed in Table 1. CPR-739 has several advantages as a core material, including:

- Four-times expansion of components
- Machinability of cured foam
- Environmental and fatigue resistance

Among the disadvantages of this foam are its sensitivity to ambient temperature (65° to 80°F) for proper foaming action, and the fact that foam density cannot be controlled at the mixing point.

CPR-739 was considered the most promising core material and was selected for the study of core/face bonding.

Sand-Filled Rigid Polyurethane Foam. An experiment was conducted to determine whether it would be advantageous to mix beach sand with polyurethane foam to produce a sand-filled core at less cost. A dry, poorly graded, beach sand (rounded grains) was mixed with CPR-739 foam at a 15-pcf foam density. The sand additive resulted in reduced flexural properties which were not outweighed by either cost or logistic benefits. No further investigation of native material core "fillers" was conducted.

Bonding Concepts

Concepts to improve bonding between the lower facing and foam core were divided into two categories: (1) mechanical/adhesion bonds and (2) improvement of foam flexural strength and stiffness in order to eliminate the lower FRP facing. With category (1) concepts the core and facing were to be bonded by use of a combination of deformations on a panel to mechanically lock the panel to the core and transfer core shear stress into facing tension, and chemical adhesion between the foam and panel surface to transfer core shear stress.

The plastics industry has been successfully using glass fibers to reinforce both thermoplastic and thermoset foams in the manufacture of products such as automobile body parts, storage containers, skis, lunch trays, which require materials of high strength, stiffness, toughness, and dimensional stability. One manufacturer, Xentex Company (a division of Exxon Enterprises), has developed a proprietary process using a form of reaction injection molding wherein large panels of glass fiber-reinforced foam are produced (Ref 11). These panels have a variable density; the proprietary process results in concentration of the fiber reinforcement at panel edges. Depending on the method of adding the reinforcement, mechanical properties of reinforced foams have shown increases of 400% to 500%. Category (2) concepts thus sought to utilize this principle of foam reinforcement.

Category (1) Concepts. With category (1) cleats or honeycomb materials would be factory-bonded to an FRP panel. With either cleats or the honeycomb the prefabricated facing conceptually would be manufactured in 7.5 x 19.5-foot sheets (ISO container compatible) which would be positioned on the ground and the foam applied, expanded, and trimmed. Factory processes, including molds, presses, and improved quality control, would result in thinner facings having equal strength to the typical 0.25-inch FRP facing of FOMAT. The bonding of cleats or honeycomb would

then produce a facing of approximately equal thickness (0.25 inch) to that of FOMAT and, thus, would have comparable logistic burden. The primary disadvantage of the category (1) concepts was cost, since these panels incurred both labor and material charges. Two category (1) concepts were evaluated--cleated FRP panels and aluminum honeycomb bonded to FRP panels.

1. Cleated FRP Facings: The cleat concept consisted of 0.02-inch-thick by 0.25-inch-high cleats bonded on 1-inch centers to a 0.10-inch-thick panel of fiberglass-reinforced epoxy. Total panel thickness, including cleats, was 0.35 inch, and two panels could be nested to give an effective shipping thickness of 0.22 inch (logistically more advantageous than a typical FOMAT facing). A 2- by 2-foot cleated panel was fabricated and used in the construction of FOMAT. The cleated panel was positioned at the bottom of a form; foam was poured into the form, cured, and trimmed to a 2.0-inch thickness; and a 0.25-inch top facing of FRP was laminated to the foam to complete the sandwich. Beams were cut from the sandwich and tested over a 20-inch span (quarter point loading). The beams failed prematurely in core shear with a unit load of 1,280 pounds (Figure 5). From the beam tests, it was concluded that optimum design should incorporate cleats on 0.5-inch centers and that the cleated side of the panel should be sandblasted after fabrication to insure maximum adhesion between the foam and panel. Cost, based on a total panel order of 10^6 sq ft, is estimated to be approximately $4.00/sq ft. A typical load curve for a cleated beam is presented in Figure 6.

2. Aluminum Honeycomb/FRP Facings: The second category (1) concept was a sheet of 0.37-inch-thick aluminum honeycomb* glued to a 0.13-inch-thick sheet of FRP (Figure 7). A 2- by 2-foot facing was fabricated into a FOMAT sandwich using the same construction procedure as for the cleated facing. Beams were cut from the sandwich and tested over a 20-inch span (quarter point loading). Failure began in compression of the upper facing beneath a load point. The beam then yielded and experienced a form of "false" strain hardening (Figure 6) as the lower facing was further stressed. Ultimate failure occurred in tension of the bottom facing (Figure 8). The ultimate unit load of 2,784 pounds carried by the beam was equivalent to that carried by a typical laboratory-constructed FOMAT beam; however, the toughness (energy absorbing capability) of the honeycomb beam was considerably improved over the FOMAT. The unit cost based on a panel order of 10^6 sq ft for an aluminum honeycomb/FRP facing is estimated to be approximately $10/sq ft. Although the facing performed exceptionally well, the cost was considered prohibitive, with the exception of possible use in localized areas subject to high landing impact loads or with construction joints to transfer shear.

<u>Category (2) Concepts</u>. Category (2) concepts eliminated the bottom facing altogether and depended on embedded fibers to impart additional flexural strength and stiffness to the foam core. The foam depth was increased, thus the surfacing load response was similar to a slab rather

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*One-quarter honeycomb cell diameter - 5052 aluminum temper - 0.004-inch foil thickness.

than a thin plate.* Flexural stresses at the bottom of the slab were thus reduced, compared to those of FOMAT, as a result of the increased surfacing thickness. Two concepts were evaluated--(1) steel-fiber-reinforced foam and (2) glass-fiber-reinforced foam.

1. Steel-Fiber-Reinforced Foam (SFRF): Steel fibers (0.010 x 0.022 x 1.0 inch) for use in fiber-reinforced concrete were mixed with CPR-739 foam components. Beams were cut from the cured foam billet for testing in flexure. When released from the billet, however, the beams curved and distorted to such an extent that testing was impossible. Inspection of the billet revealed that it was bowed slightly. The bowing was attributed to the large differences between the thermal characteristics of the steel and the polyurethane foam. The exotherm from the curing foam caused the steel fibers to elongate, and when the foam billet cured, thermal stresses were locked into the foam by the randomly oriented steel fibers. From experience with SFRF, it was concluded that any facing or reinforcement added to, or used in conjunction with, the CPR-739 core must have similar thermal characteristics. Thus, any facing or embedded reinforcement concepts utilizing aluminum, steel, or any of the common engineering metals were eliminated.

2. Glass-Fiber-Reinforced Foam: Chopped fiberglass strands were added to 20-pcf-density CPR-739 foam during mixing of the two foam components. Two lengths (0.50 and 1.0 inch) of glass strands were used initally, and fiber content - percentage by weight of foam - was varied. Beams fabricated with the 0.50-inch fibers failed through debonding of the fibers, which were too short to be sufficiently anchored in the foam (Figure 9). The 1.0-inch-length fibers were then tried; only 2.5% were required to achieve comparable strength properties. Manual mixing of fibers proved difficult and produced erratic batch strengths, which were dependent on the number and size of air voids introduced into the mixture and the degree of glass fiber dispersion.

Specifications were drafted and a contract was awarded for the fabrication of a bench model machine capable of simultaneously mixing and spraying the two foam components and chopping glass fibers into the path of the foam (Appendix A). Higher loadings of glass fiber filler (10% by weight with fiber lengths adjustable from 1/4 to 2 inches) and, in comparison with the manual mixing method, improved batch quality were obtained with the spray machine.

The spray machine was adopted for all subsequent foam production. With the machine, both unfilled and glass-fiber-filled slabs of CPR-739 foam were produced and cut into beams and tested under quasi-static loading to determine flexural and compressive characteristics (Figures 10, 11, and 12). Glass fiber reinforcement at 10% by weight of 20-pcf CPR-739 foam, resulted in an 82% increase of elastic modulus (bending) to 73,000 psi and provided a corresponding 71% increase in flexural strength to 1,567 psi (Table 2, batches AS1 and CS5). Compressive strength and modulus remained relatively constant at approximately 1,100 psi and 25,000 psi, respectively (Table 3). The constant compression characteristics reflected the fact that the fiber reinforcement was

*FOMAT.

primarily lying in planes normal to the direction of compressive loading. This is an entirely acceptable result since the unfilled foam was sufficiently strong in compression and primarily required increased flexural strength and modulus.

From the various static tests, it was concluded that 20-pcf foam was the lowest density foam that could be considered as a core material for a medium duty surfacing and that a significant flexural strength or stiffness gain could be realized with the addition of a fiberglass filler. Glass-reinforced 20-pcf foam with a fiberglass-reinforced surface facing (termed FIBERMAT) was judged to be superior to the other surfaces studied with respect to ease of field construction and cost in-place and was rated equivalent with respect to strength. Therefore, FIBERMAT was regarded as the more logistically and technically feasible of the concepts and was selected for further evaluation.

FIBERMAT CONCEPT EVALUATION

FIBERMAT was subjected to a series of laboratory tests and analyses structured to evaluate more completely its potential for fulfilling the requirements for a medium duty airfield surfacing. Previously conducted quasi-static tests give ultimate material properties and characteristics in bending and compression. Additional tests of fatigue and environmental resistance were specified to provide data which were used to select working stress levels (safety factors on ultimate strength) for a FIBERMAT surfacing. The known material characteristics were input to a finite element computer code - SLIP (Ref 15) - for analysis of wheel-load-induced pavement stresses. The safety factors enabled meaningful interpretation of the computer-predicted stress levels, thus facilitating design of FIBERMAT pavement sections for each of the designated EAF traffic areas for the wheel load critical to each area. Pavement section designs were completed for an airfield constructed over soil with a strength of CBR 4 and for an airfield over soil of CBR 10. By use of these sections, estimates of logistic burden - shipping cube and weight and material cost - were formulated.

Fatigue and Life Expectancy

Experiments and analyses have provided data which indicate that FIBERMAT can be economically designed such that aircraft-induced stresses are well below ultimate static stresses; however, pavements eventually fail at stress levels below ultimate as a result of fatigue produced by repeated loadings. For this reason, beams of FIBERMAT were tested to determine their fatigue resistance.

Beams were tested under third point loadings at various maximum stress levels. In load repetitions applied, fiber stress was cycled from zero to maximum to zero every 2 minutes (frequency of 0.5 cpm). For the given frequency, the fatigue characteristics of FIBERMAT were

found to be quite similar to those of plain portland cement concrete (*Figure 13*). *Extrapolation of data revealed that*, below stress ratios of 44%, FIBERMAT was capable of sustaining an infinite number of load repetitions (> 10^6).

To gain some perspective as to the implication of this fatigue life, a method described by Yoder was utilized (Ref 16). The number of stress repetitions and the corresponding stress level were calculated for the main runway of an EAF and a soil CBR of 4%. The fatigue estimate was simplified by the conservative assumption that 60 F-4B aircraft were operating from the field at a sustained rate of five sorties per day per aircraft over a 365-day period.* The percent of used pavement fatigue was determined by dividing the calculated stress level of the surfacing for an F-4B wheel load by the surfacing ultimate stress to determine a stress ratio. By entering Figure 13 with the stress ratio, the allowable repetitions to failure were determined. Thus,

$$\%\ \text{Used Fatigue Life} = \frac{\text{Actual Load Repetitions}}{\text{Allowable Load Repetitions}}$$

where the actual load repetitions were found by accounting for aircraft lateral wander - 7.36 sorties per coverage (Ref 4).

The computations determining the amount of expended fatigue life based on use of an F-4B aircraft are summarized below.

Computation Basis	Value
Equivalent Single Wheel Load	27 kips
Stress	369 psi
Stress Ratio	0.25
Sorties	109,500
Actual Load Repetitions	14,878
Allowable Load Repetitions	10^6
Fatigue Factor Used	2%

The surface is FIBERMAT with the following characteristics: 0.125-inch top face thickness per 4.5-inch core thickness and 20-pcf core density with 2.5% (by weight of foam core) glass fiber. Ultimate bending stress of the bottom surface is 1,500 psi.

A year of operations would use only on the order of 2% of fatigue life; therefore, fatigue is not expected to be a controlling factor for surfacing life. The foregoing procedure did not consider, however, any

*All MAG aircraft operations were considered in terms of the F-4B (heaviest wheel load/tire pressure) to present a conservative estimate of fatigue life. A sortie equals one takeoff and one landing.

gradual, permanent, shear deformation of the underlying subgrade and the resultant increase in pavement surface deflection. Subgrade deformation probably will be the determining factor for FIBERMAT surfacing over low strength soils. Life expectancy, with respect to subgrade deformation, cannot be reliably predicted by analytical methods and can be determined only through field traffic tests.

Environmental Performance

Laboratory-prepared specimens of FIBERMAT and FOMAT were subjected to environmental cycles (Table 4) to measure durability with respect to extreme weather conditions during service life. Each cycle covered a total period of 1 week, and cycles were continued for 21 weeks. Material performance was monitored to determine:

1. Whether the foam would absorb sufficient moisture during immersion to deteriorate during subsequent freezing periods
2. Core susceptibility to degradation in a warm and wet environment
3. Core/facing delamination from temperature extremes
4. Changes in general strength characteristics

Exact correlation of laboratory environmental cycles with anticipated service life under field conditions was impossible. The cycles spanned 5-1/4 months and should represent a service life - with respect to ambient conditions specified previously under operational requirements - in excess of the 1-year period for temporary construction.

FIBERMAT and, to a somewhat lesser extent, FOMAT exhibited good short-term endurance to weathering. A lack of any apparent foam distress was interpreted as indicating negligible absorption of water since the freeze cycle (-70°F) immediately followed the immersion cycle. None of the beam samples suffered any core/facing delamination even with temperature extremes of -70° to 160°F. Flexure tests of beams indicated constant strength for FIBERMAT samples and constant stiffness for FIBERMAT and FOMAT samples (Figures 14 and 15). A slight trend toward lower flexural strength with increasing number of cycles was recorded for FOMAT. From visual observation of failed beams, the FOMAT strength decrease may have resulted from temperature fatigue of the foam core at the interface between the core and lower facing. Cycling did not affect either compressive strength or stiffness of the foam (Figures 16 and 17).

In conclusion, FIBERMAT had somewhat better resistance to extreme environments than FOMAT. Both pavements are projected as having adequate weathering resistance to meet the specified operational requirements.

Pavement Design and Logistic Analysis

Analyses were conducted to predict the weight, material cost, and cube logistics factors for an EAF constructed on subgrades having strengths indicative of CBR's of 4% and 10%. Derivation of logistic factors

necessitated design of variable depth pavement sections for the traffic areas depicted in Figure 2. The pavement sections were designed with consideraton of soil strengths and critical load parameters applicable to the traffic areas. Designs incorporated factors of safety on ultimate surfacing stresses (Table 5).

The safety factors were based upon engineering judgment and consideration of traffic quantity, type of traffic, load nature, fatigue data, and criticality of the traffic area with respect to the operation of the EAF. The center portion of the runway - which is subject to 75% to 100% of all traffic, is critical to EAF operation, and receives roughness-induced dynamic loading during takeoff - was designed with a safety factor of 3.0, the highest allocated. Runway edges, which experience less traffic, and the medium duty parking apron, which is less critical to EAF operation, were assigned a safety factor of 2.5. The runway traffic area subject to landing impact was designed for landings of the F-4 in a taildown attitude at a sink rate of 17 fps. From Figure 18 only 10% of F-4 landings will occur at a greater sink rate; thus the pavement would be capable of withstanding on the order of 90% of all landings with the opportunity of making repairs to local failures caused by those few landings which exceed the design sink rate.* Safety factors of 1.1 and 1.5 on compressive and bending stresses, respectively, were assigned for design of the pavement within the landing impact traffic area. These comparatively low safety factors were believed justified, as they reflected a factor of safety on a seldom-encountered, extreme loading condition. Compression of the upper foam would be the least critical failure mode, resulting in some local delamination of the FRP facing; thus, it was assigned the lower value.

Design aircraft loads for the various traffic areas are given in Table 6. The analyses of pavement sections were conducted with the aid of the finite element computer code SLIP, developed at the University of California by E. L. Wilson and modified by CEL (Ref 15). The modified code uses the finite element method and elastic theory to compute the principal elemental stresses and strains within a layered pavement system. The critical stresses predicted for the various pavement sections utilized in the logistics calculations are presented in Tables 7 and 8.

Surfacing material weights, cost, and shipping volume for airfields having soil CBR values of 4% and 10% were tabulated in Tables C-1 and C-2. These logistic factors were then plotted with respect to soil strength (Figure 19) to give an indication of FIBERMAT logistic performance compared to that of AM2 airfield matting. AM2 matting, being prefabricated, exhibits constant logistic factors over the entire soil strength range. FIBERMAT, however, becomes more logistically advantageous as soil strength increases.

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*From comparison of tire load/deflection characteristics and landing characteristics (Figures B-1 through B-4 in Appendix B), the F-14 is found to represent a much less stringent design aircraft with respect to landing impact. With probable obsolescence of the F-4 in the 1980's, the F-14 would be the leading candidate for use in landing impact calculations.

When constructed on soil having a CBR of 10%, FIBERMAT cost is approximately one-half that of AM2. FIBERMAT would reduce shipping cube requirements by 56% (CBR 10) as a result, primarily, of the lack of dimensional standardization inherent in AM2 matting -- bundles 12 feet in length do not efficiently pack into 8 x 8 x 20-foot containers. Given a breakbulk shipping mode, however, AM2 would present the lower cube requirement; additionally, AM2 would be more advantageous with respect to an aerial shipping mode as a result of its lower weight (CBR < 10). Thus, soil strength of CBR 10 is the "break even" for cube and weight logistic factors.

FIBERMAT will seal the underlying subgrade from the degrading effects of moisture, thereby prolonging service life. To achieve comparable performance, AM2 matting would have to be placed either upon stabilized soil (not logistically feasible) or over a membrane. Use of a typical membrane, WX 18, would add a logistic penalty on the order of $1.00/sq ft in cost and 0.44 lb/sq ft in weight (Ref 19). The life expectancy of the membrane would be questionable. The curves representing AM2 logistic factors in Figure 19 do not reflect the additional logistic burden of a membrane.

CONSTRUCTION CONCEPT

Development of either concepts or equipment for field construction of FIBERMAT was not specifically included in the current scope of work. However, applicability to field construction was a prime factor in evaluation of the feasibility of the various FOMAT bonding concepts and of the FIBERMAT concept. Thus, a preliminary construction method was conceptualized for FIBERMAT.

Conceptually, the airfield subgrade would be graded to within a tolerance of ±1/8 inch, using automated controls on a conventional table of equipment motor grader. The control system, similar to one developed at CEL, would utilize a reference plane established by a ground-based rotating laser beam interacting with a light-sensitive receiver mounted on the motor grader (Ref 20). Finish grading would be followed by application of fiberglass-reinforced foam using either a spray technique or a modified form of reaction injection molding (RIM). The apparatus would be transportable in an ISO container and would be mountable on a standard logistics trailer for field work. The spray equipment would chop fiberglass roving into the foam spray pattern while maintaining the temperature of components (prior to spraying) within a range of 60° to 75°F.

After rising and cure, the foam would be trimmed by a motor grader equipped with a revolving motorized drum coated with abrasive particles (e.g., carborundum) in lieu of the conventional moldboard.* The drum attachment would be designed to be bolted to the grader and would be

*A similar modified grader has been developed by the equipment industry for planing and removing asphalt from roads (Ref 21).

used in conjunction with automated controls to give a finished surface to within a ±1/8-inch tolerance. Finally, fiberglass-reinforced polyester resin would be laminated to the foam.

The AMSS module (Figure 20) would be utilized for laminating FRP to the foam. The AMSS module would be slightly modified with a resin bath replacing the hoses and spray gun. Fiberglass cloth would be fed along rollers and into a tank containing catalyzed resin, where complete impregnation would occur. Leaving the tank, the cloth would pass between two doctor blades, which would remove excess resin, and thus control the resin-to-fiberglass ratio.* The impregnated fiberglass cloth would next be laid against the trimmed foam and rolled by a set of rollers trailing the logistics trailer (Figure 21).

DISCUSSION OF TECHNICAL RISK

Twelve factors are considered as constituting the technical risk inherent to the development of the surfacing concept:

1. Static Load Capacity
2. Fatigue Resistance
3. Environmental Weathering Resistance
4. Temperature Effects (jet exhaust)
5. Impact Resistance
6. Face/Core Bonding
7. Cost
8. Ambient Temperature Effects
9. Trafficability
10. Construction Technique
11. Storage and Distribution Logistics
12. Flammability

Prior efforts by others (Ref 3) and FY-77 research have mitigated the risk represented by factors 1 through 7. Environmental temperature effects and flammability are the subject of FY-78 research; and traffic testing (key project milestone) will be completed in FY-79. The relative surfacing performance** in FY-79 will be critical to (1) continuance of

*The conceptual impregnation method is analogous to that used by the resin industry to create pre-impregnated (Pre-Preg) reinforcements (Ref 22). This method is within the current state-of-the-art and would add only minimal cost to the AMSS module.

**The degree of enhancement of load performance with respect to current mattings.

the project and (2) the extent of research effort merited to reduce technical barriers associated with field construction techniques and logistics. The development cost of prototype construction equipment is dependent on whether the material components may be spray-applied (lowest cost and risk). Consideration of costlier alternative methods would require substantially improved trafficability (benefits). A subjective estimate (based on an arbitrary scale of 100) of the technical risk is plotted with respect to fiscal year in Figure 22. At the start of the project (origination of FOMAT concept), the technical risk is judged as having been extremely high and is projected as being moderate by the end of FY-79 and low by the start of scheduled advanced development work in FY-81. The risk levels were defined as follows:

Extremely High Risk - Requirements are far in advance of existing technology; a major breakthrough in technology is required.

Moderate Risk - Advance in technology is required; precedence for such advance does exist or the advance is a natural continuation of present trends in technology.

Low Risk - Basic technology exists; major difficulty is adapting existing technology to the problem and developing required designs and procedures.

CONCLUSIONS

The bonding deficiency associated with the core/lower face bond of field-constructed FOMAT can be corrected by (1) incorporating into the sandwich design a prefabricated lower facing with honeycomb providing shear transfer between core and facing or (2) redesigning to eliminate the bottom facing requirement by increasing core flexural strength, elastic modulus, and surfacing depth (FIBERMAT concept). Of these, FIBERMAT is the more cost-effective concept. FIBERMAT possesses adequate fatigue strength and weathering resistance with respect to its intended usage as a temporary, medium duty airfield surface.

Additionally, core materials to be used as alternatives to rigid polyurethane foam were investigated - syntactic foam and foamed polyester resin. Polyester-resin-based syntactic foam is logistically deficient. Foamed polyester resin is rated as a potentially superior core material, but requires a major advance in the state-of-the-art to lower the toxicity of the chemical foaming agent.

RECOMMENDATIONS

Although a high technical risk is involved, the development of the FIBERMAT concept as a temporary, expedient, medium duty airfield pavement is regarded as feasible. Technical risk has been reduced since project initiation, and delineation of the remaining areas of high technical

risk made. FY-81 is recommended as a target for the initiation of prototype equipment development and validation for the subject surfacing concept. Achievement of the following major milestones is recommended to further reduce technical risk and to conclude feasibility evaluation of field construction of an expedient medium duty airfield pavement:

Evaluation of environmental temperature effects and development of joint concepts

Medium duty traffic testing

Construction concept development

It is further recommended that a separate project be established within the horizontal construction subobjective of the Advanced Base Mobility Program (Ref 23) to develop concepts for the logistic storage, shipping, handling, and transferring of the chemicals comprising the AMSS and FIBERMAT systems.

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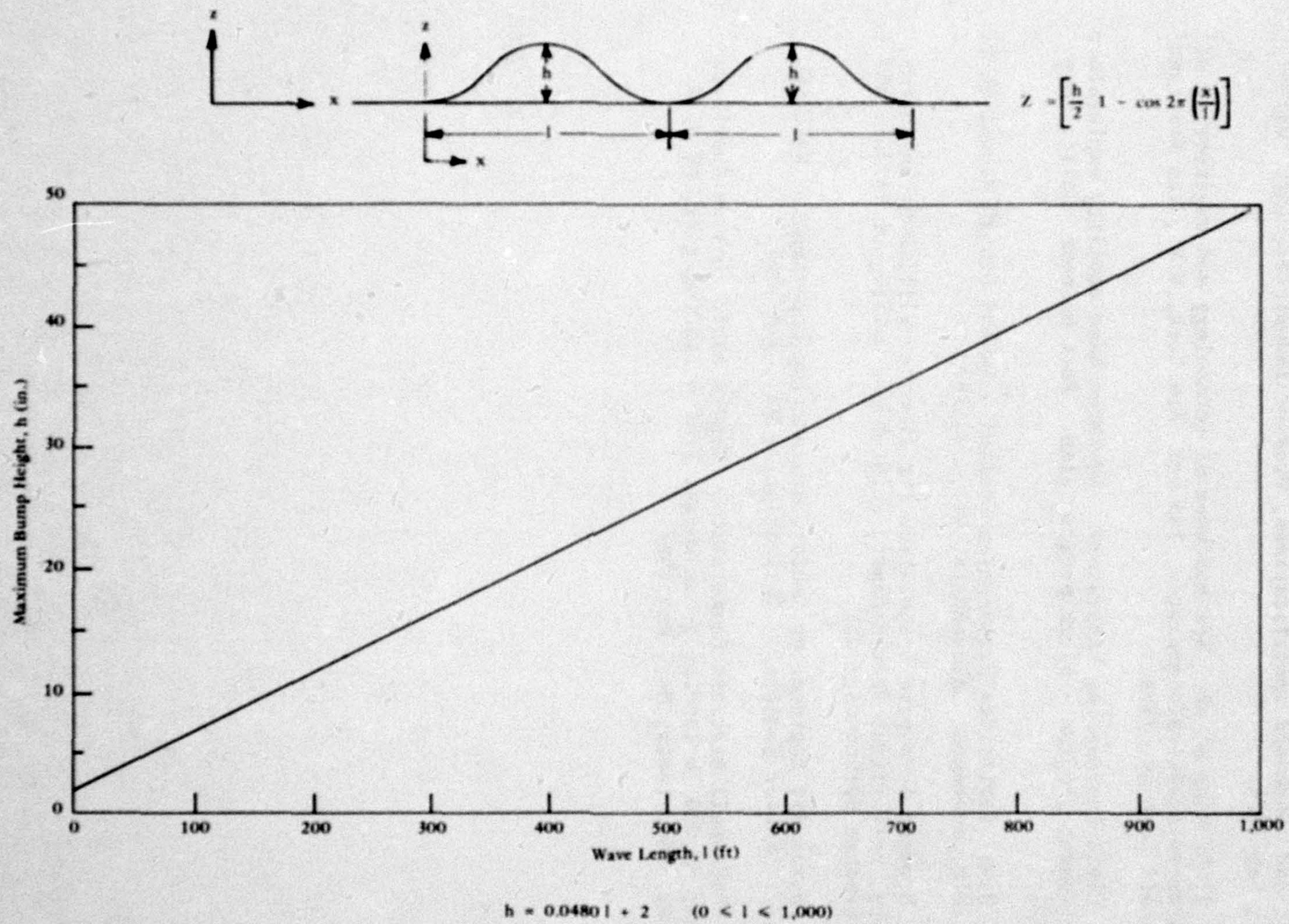


Figure 1. Ground roughness for landing and takeoff (Ref 20).

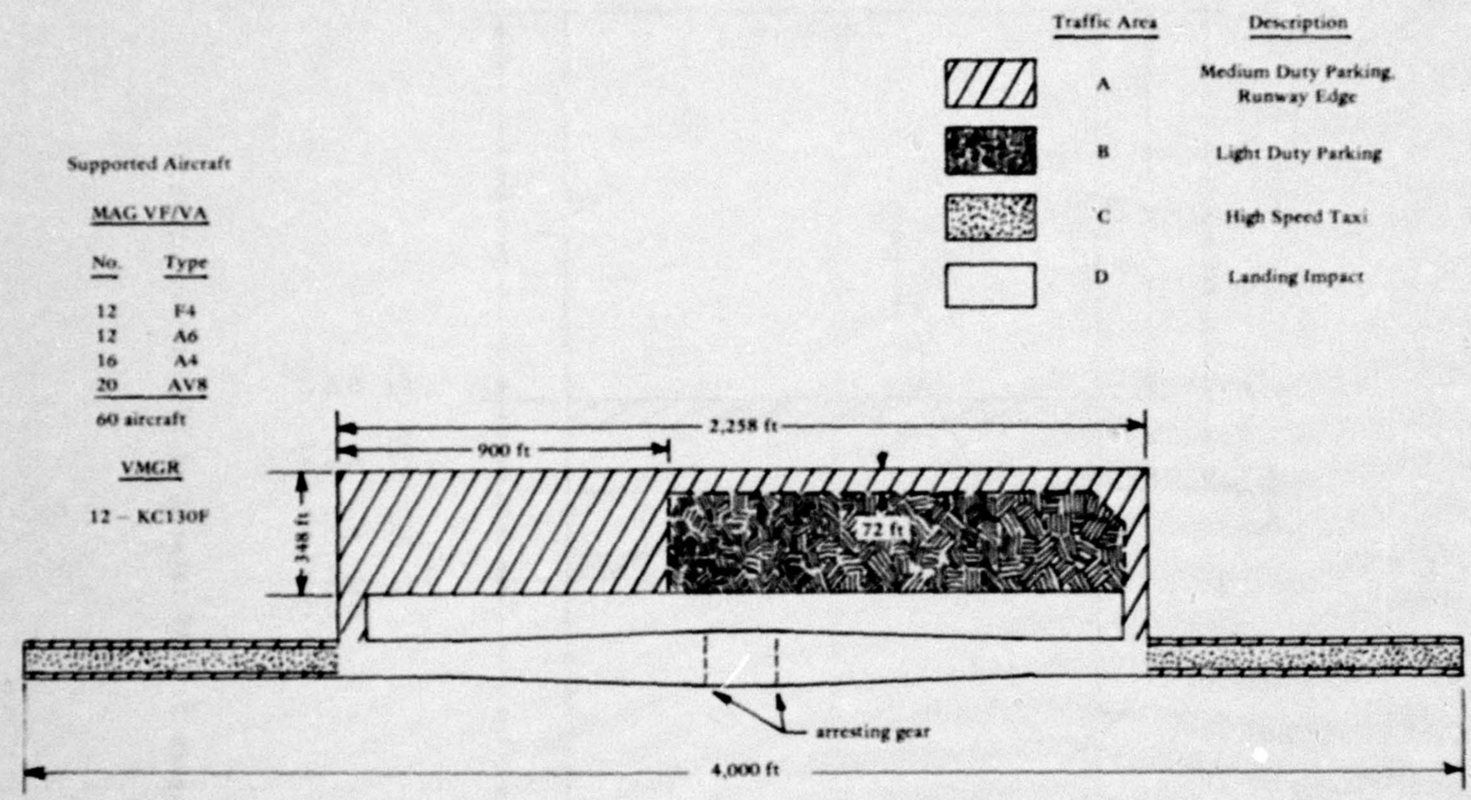
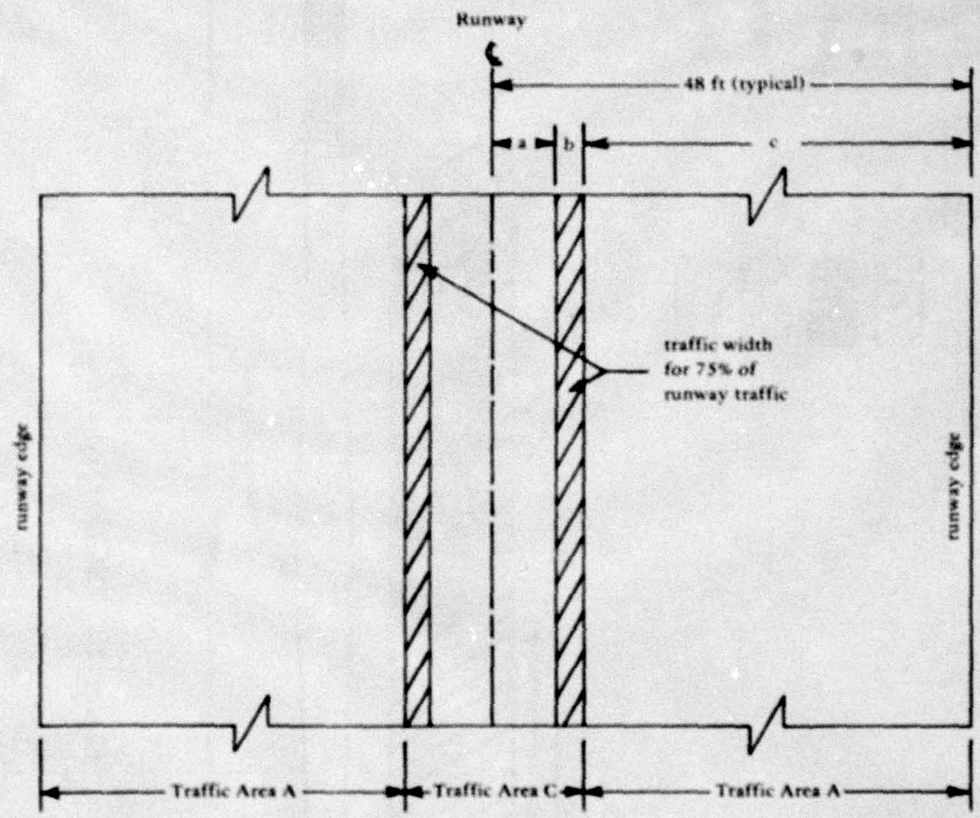


Figure 2. EAF traffic areas.



	a (ft)	b (ft)	c (ft)
F-4J	9	3.3	35
C-130	7.2	3.3	36
C-141	8.8	3.3	34

Figure 3. EAF lateral traffic distribution.

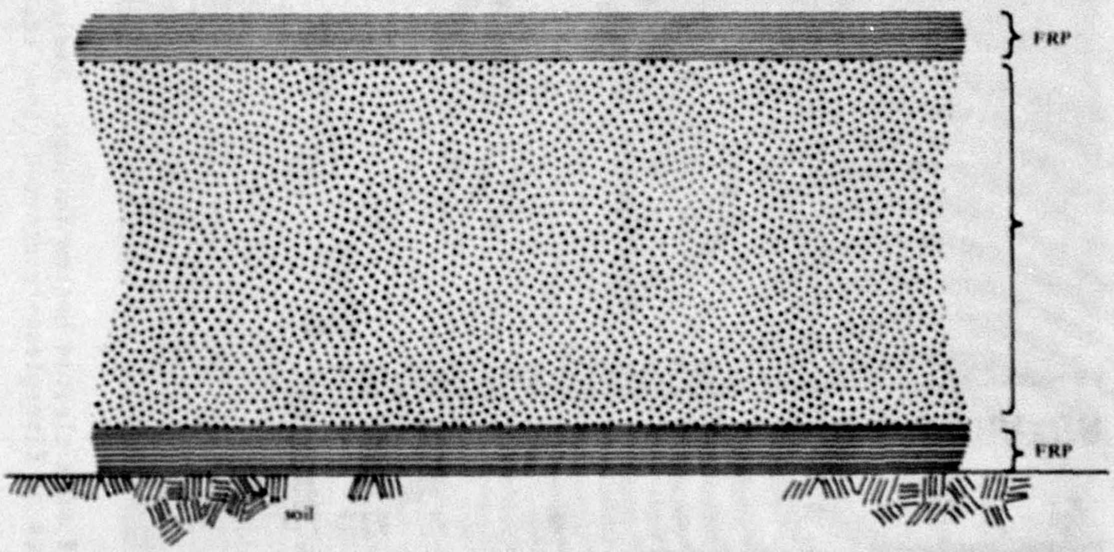


Figure 4. Typical FOMAT construction (two fiberglass facings on each side).

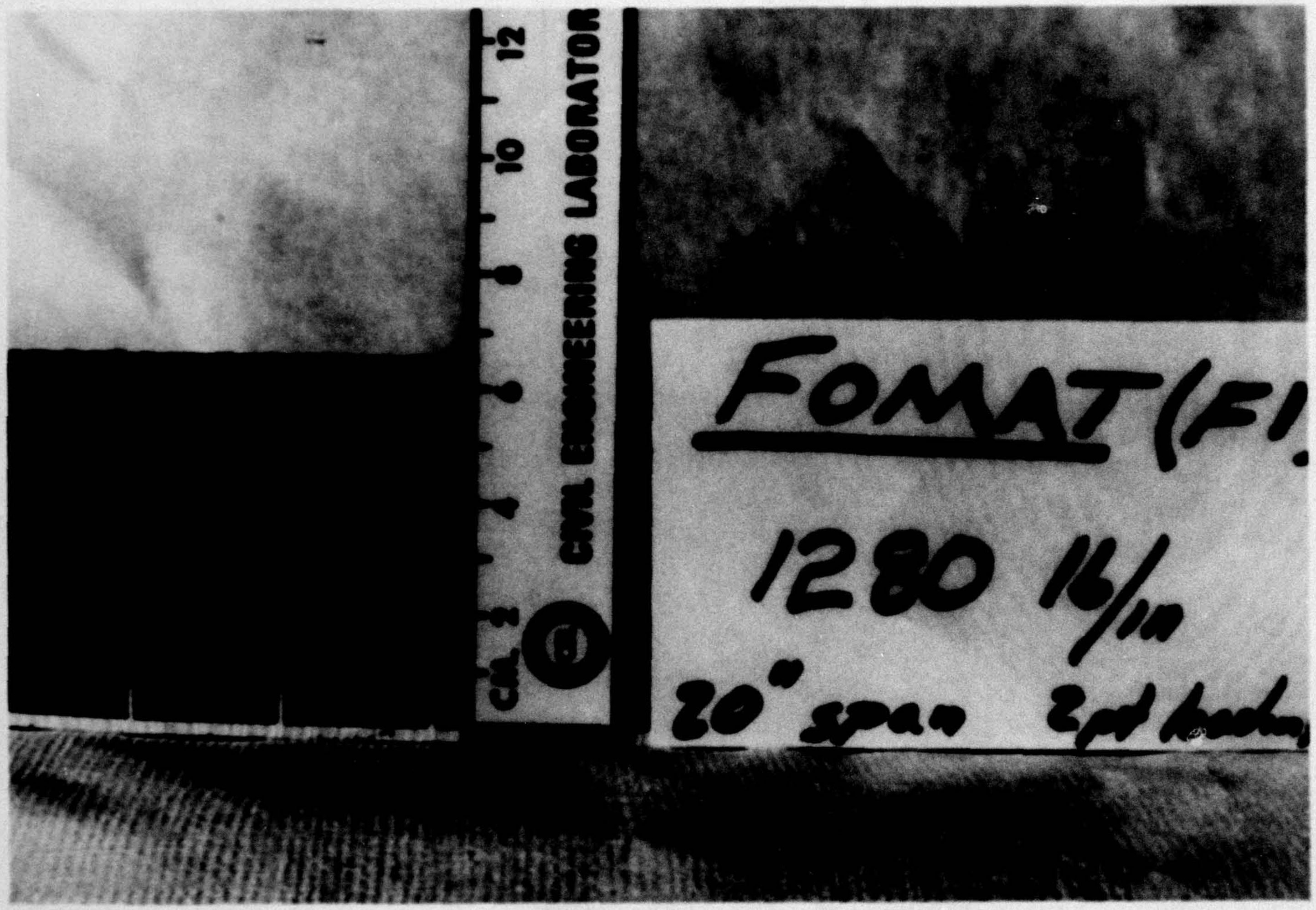


Figure 5. FOMAT with cleated bottom facings. Facing and cleats of fiberglass-reinforced epoxy resin.

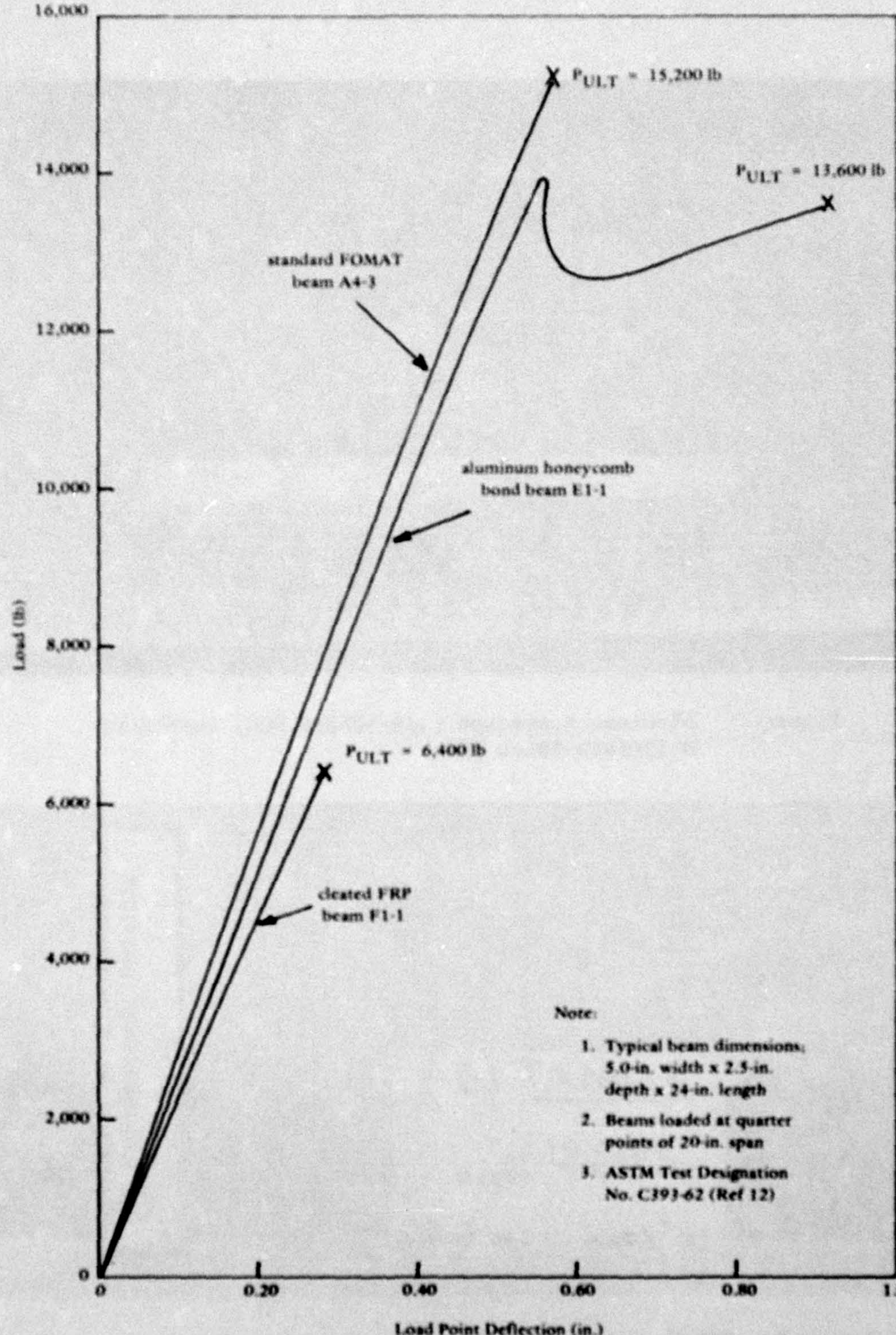


Figure 6. FOMAT beam load-deflection characteristics.

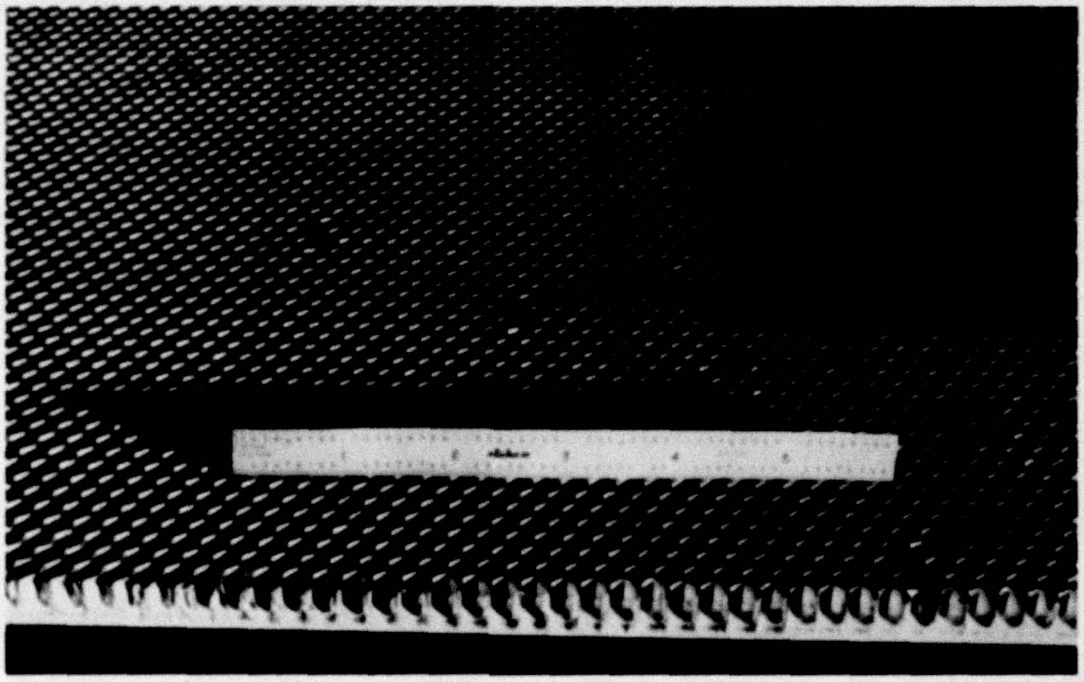


Figure 7. Aluminum honeycomb (1/4-5052-0.004) bonded to 0.13-inch-thick FRP.

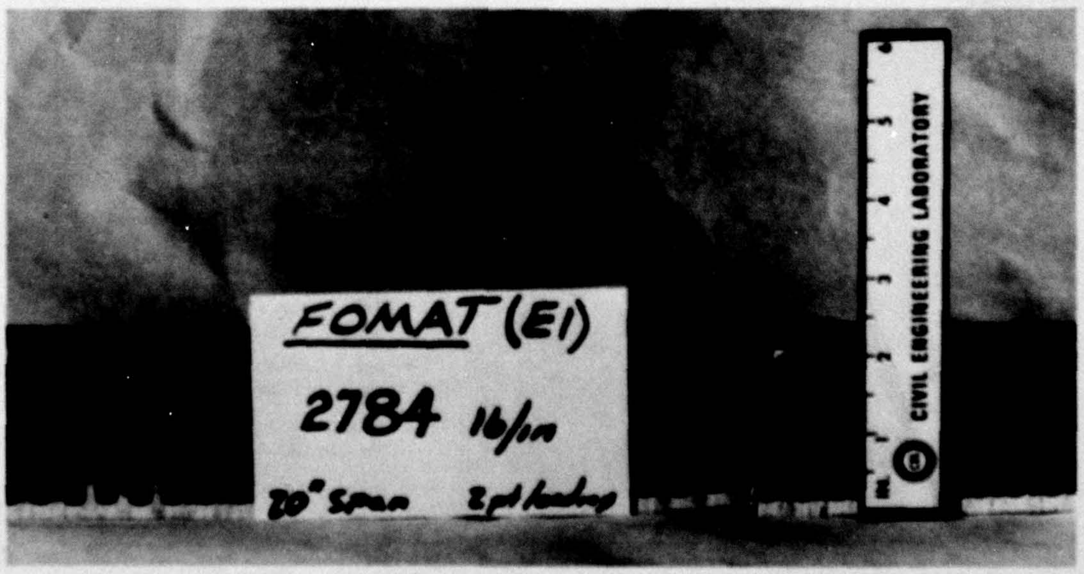


Figure 8. FOMAT with bottom facing of aluminum honeycomb bonded to FRP. Upper facing failed in compression followed by tension failure of bottom facing.

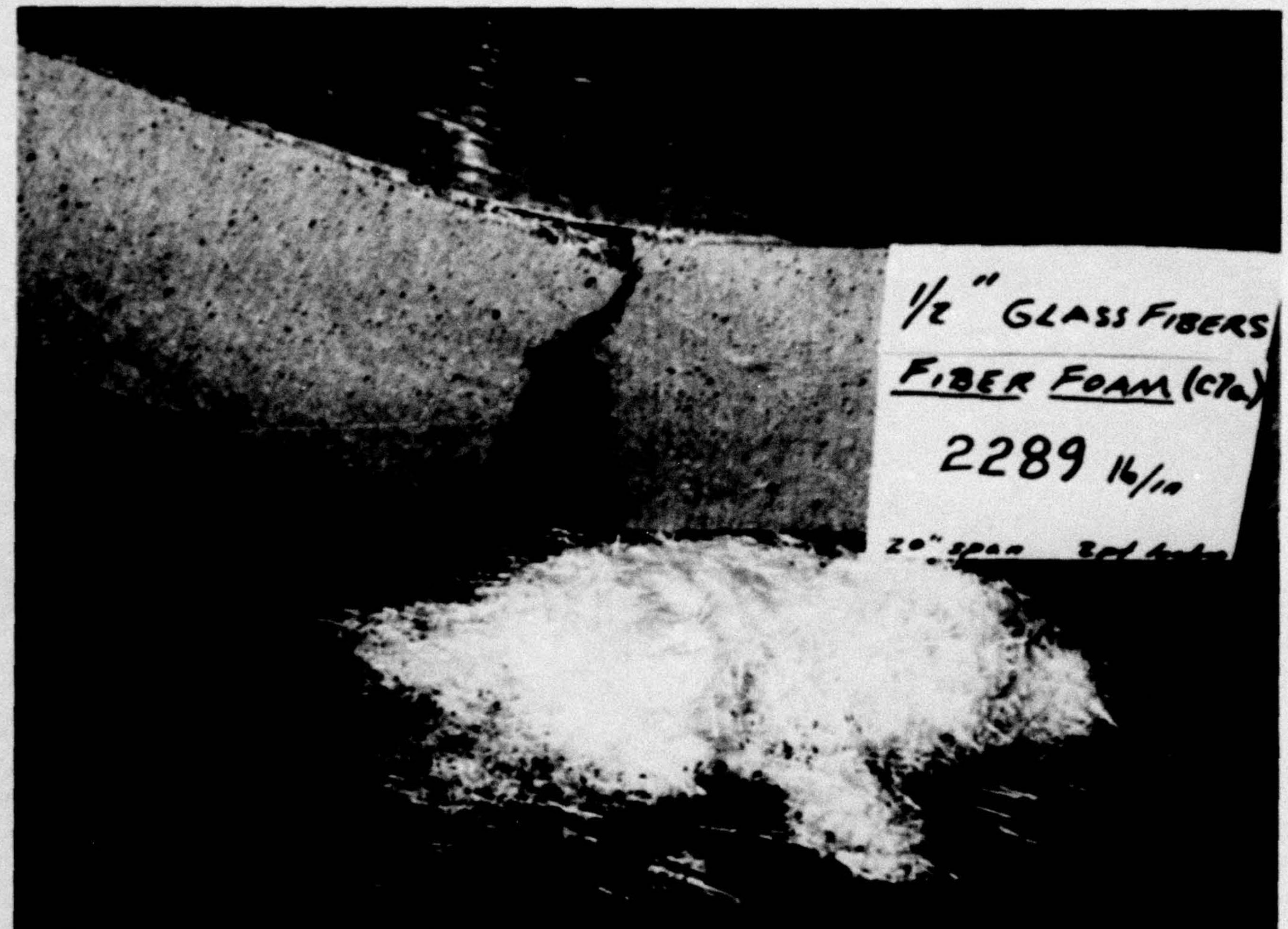
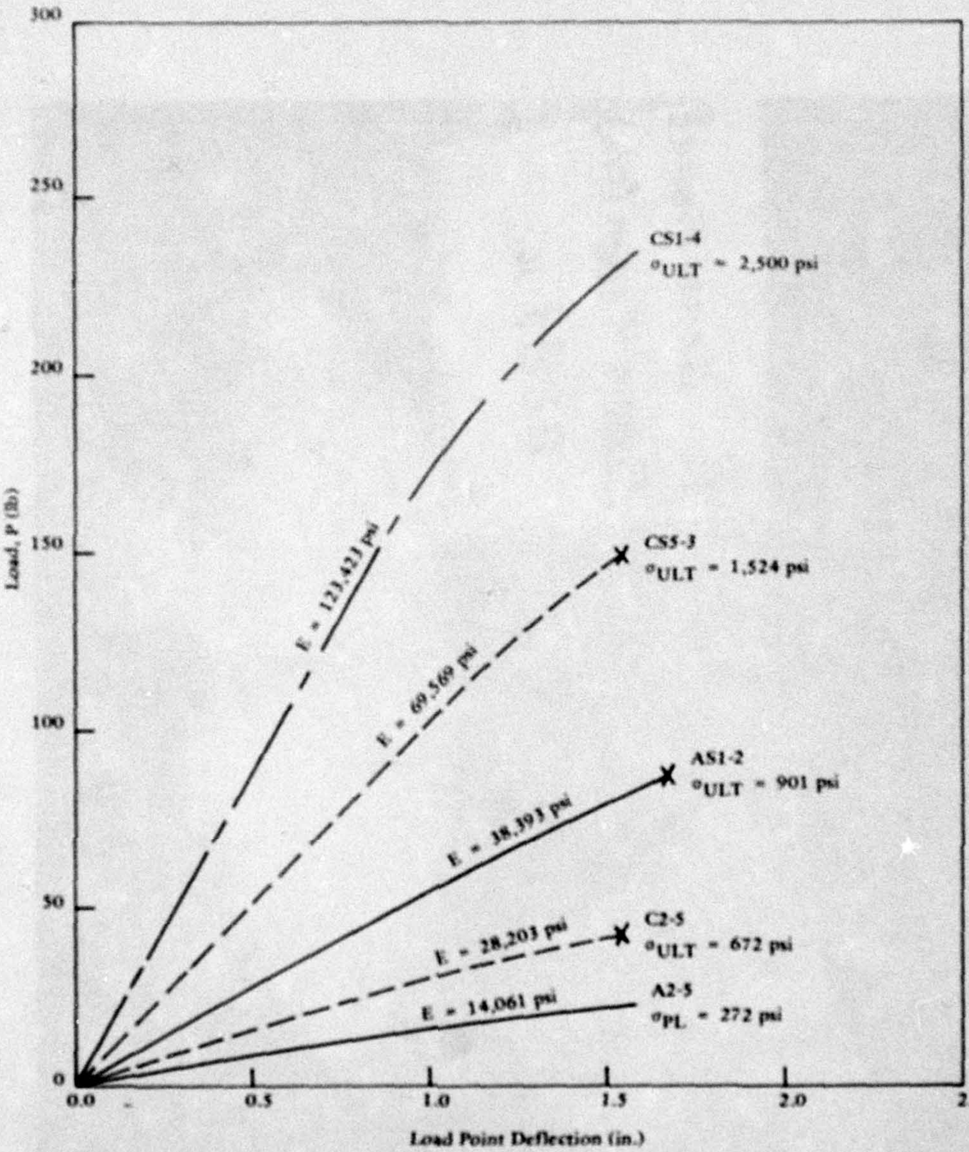


Figure 9. FIBERMAT with 20-pcf foam reinforced with 5%, 1/2-inch-length glass fibers.



Batch	Foam Density (pcf)	Span (in.)	Filler
A2	15	16	None
C2	15	16	5%, 1/2-in. glass fibers
AS1	20	20	None
CS5	20	20	10%, 2-in. glass fibers
CS1	20	20	2%, 1-1/2-in. glass fibers plus 1 layer 2010 woven roving/random fiber

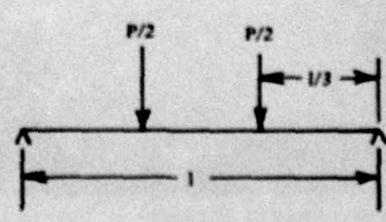


Figure 10. Typical flexural characteristics of foam core materials (Ref 13).

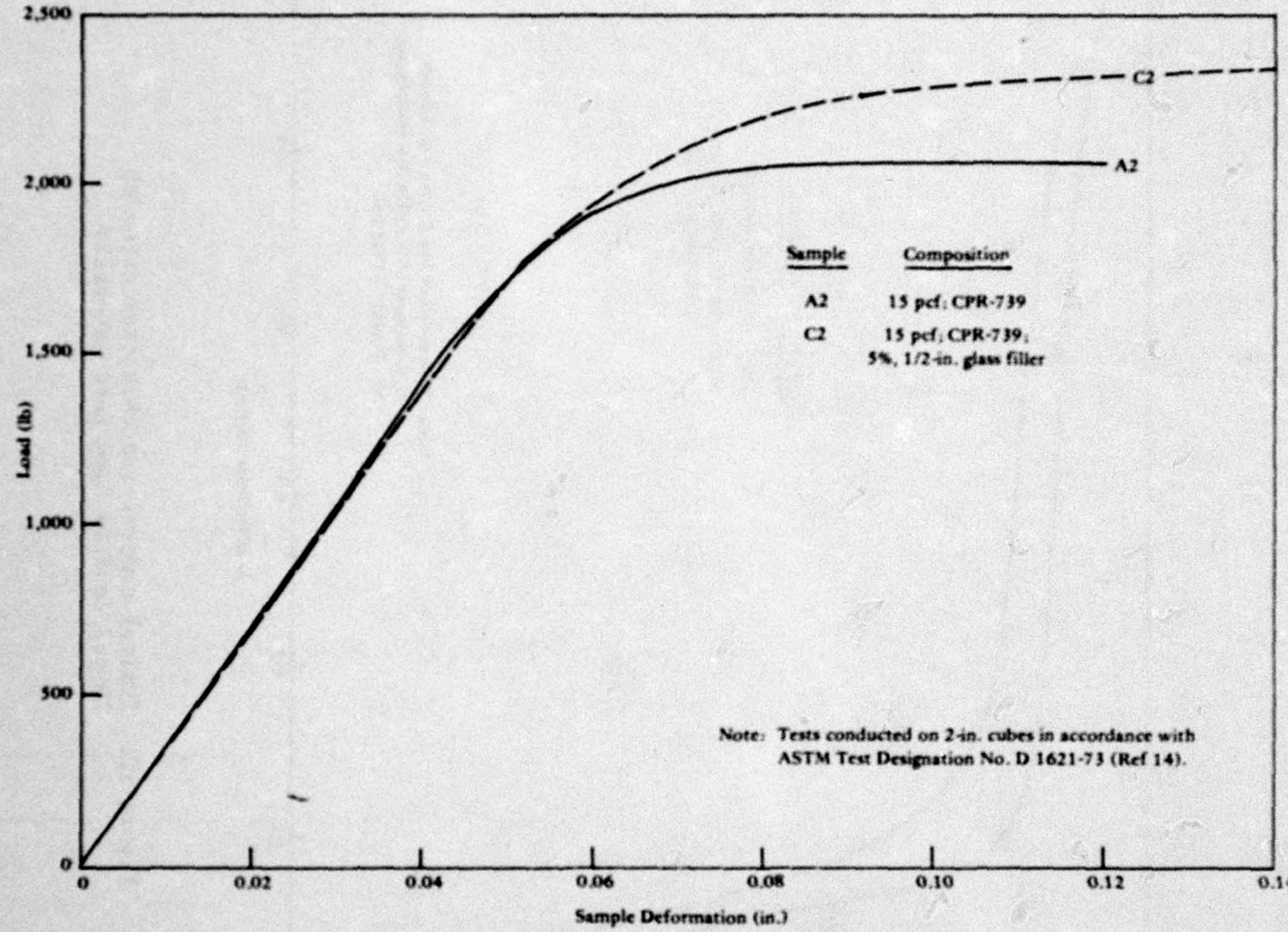


Figure 11. Typical compression characteristics of 15-pcf density foam core materials.

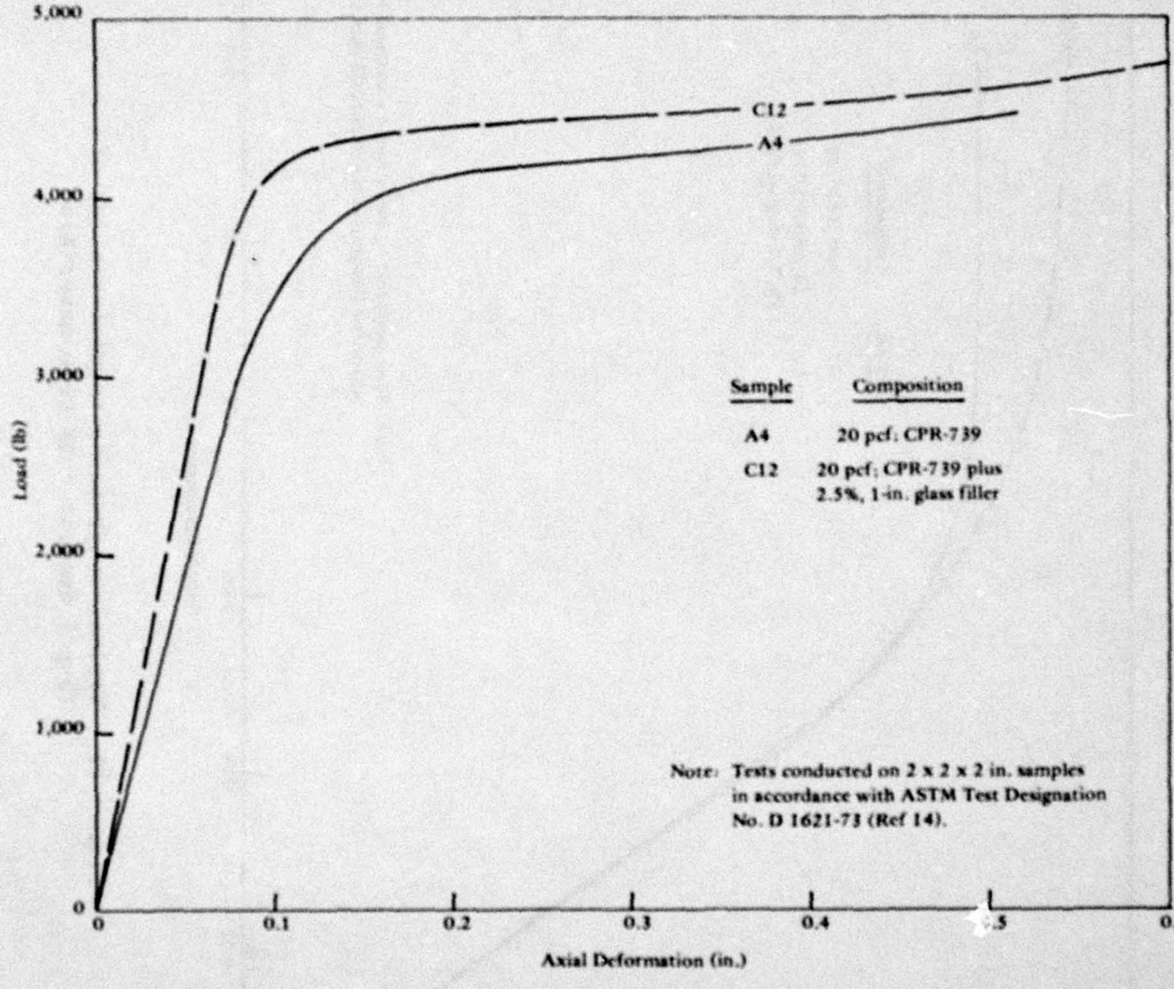


Figure 12. Typical compression characteristics of 20-pcf density foam core materials.

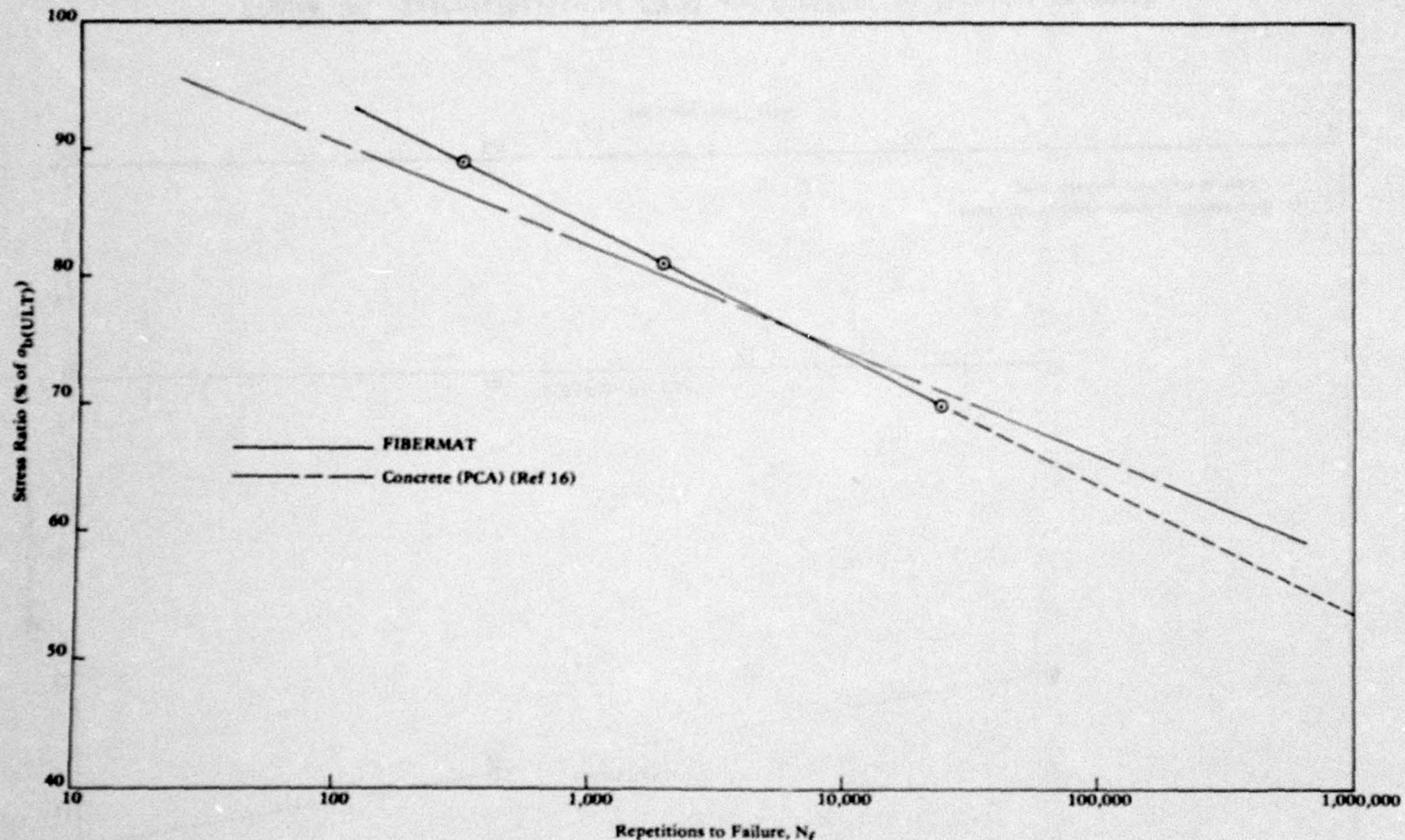


Figure 13. Fatigue curves for concrete and FIBERMAT in flexure.

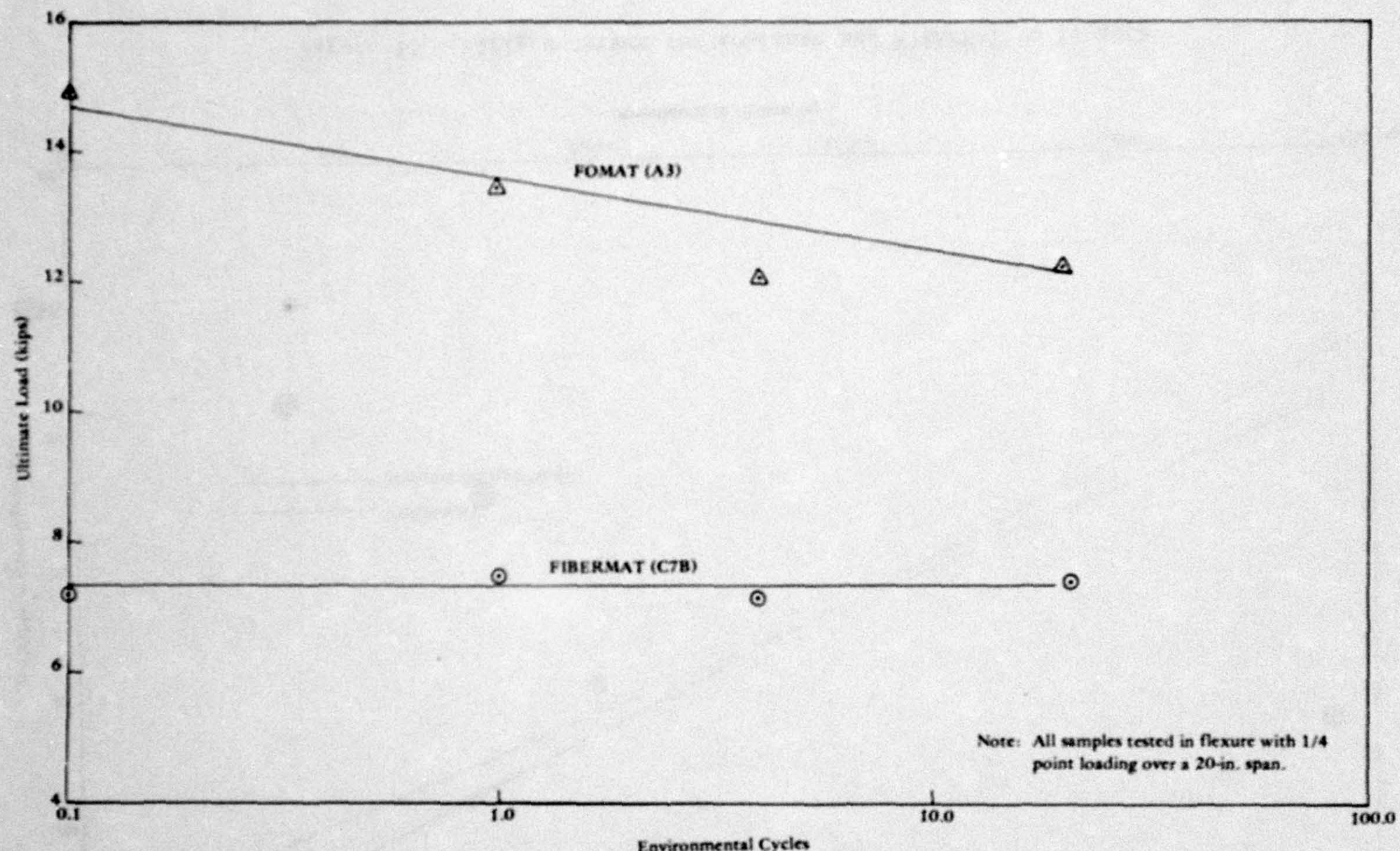


Figure 14. Susceptibility of FOMAT and FIBERMAT to flexural strength deterioration on exposure to extreme environments.

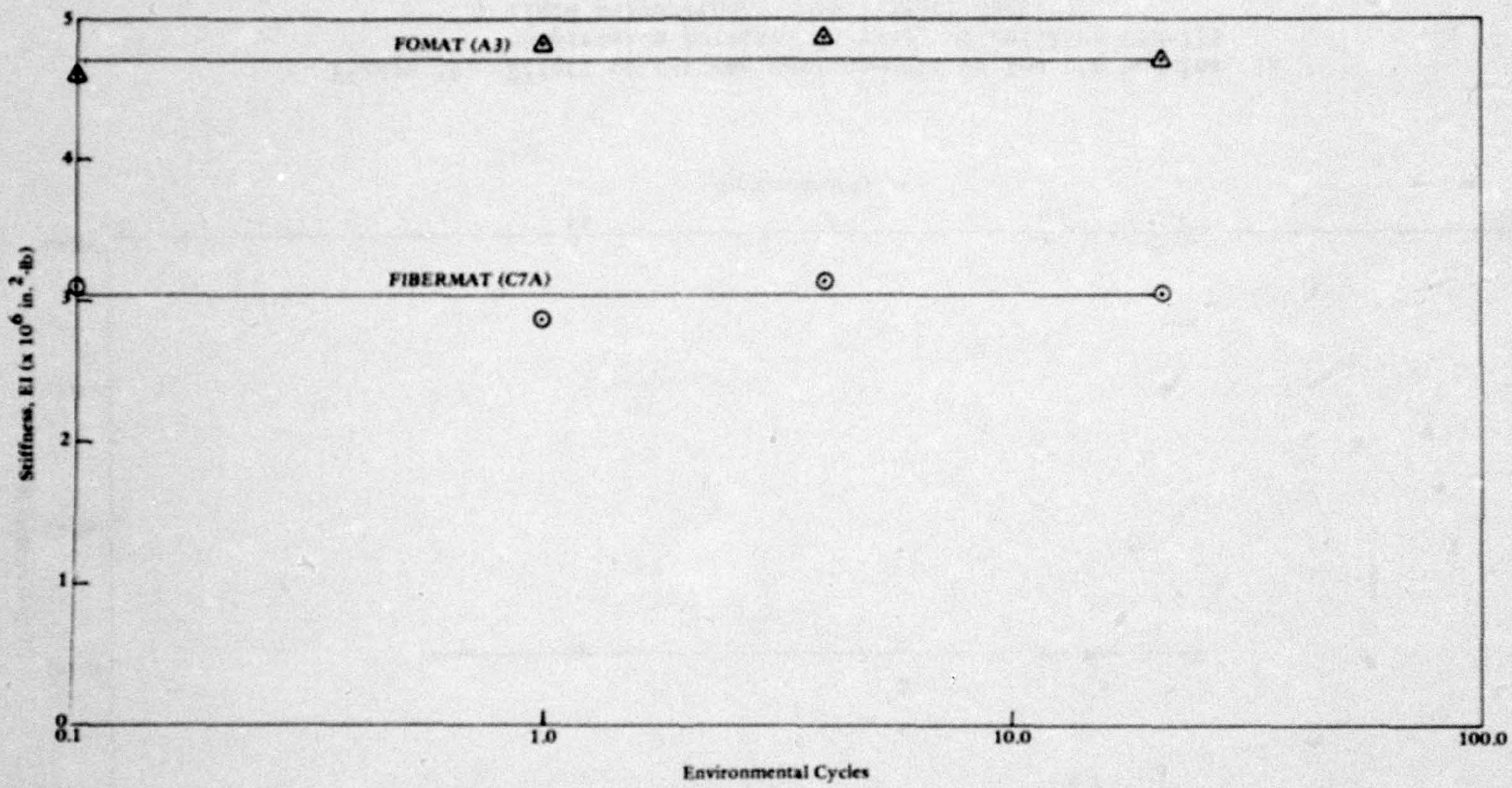


Figure 15. Effect of extreme environments on stiffness of FOMAT and FIBERMAT beams in flexure.

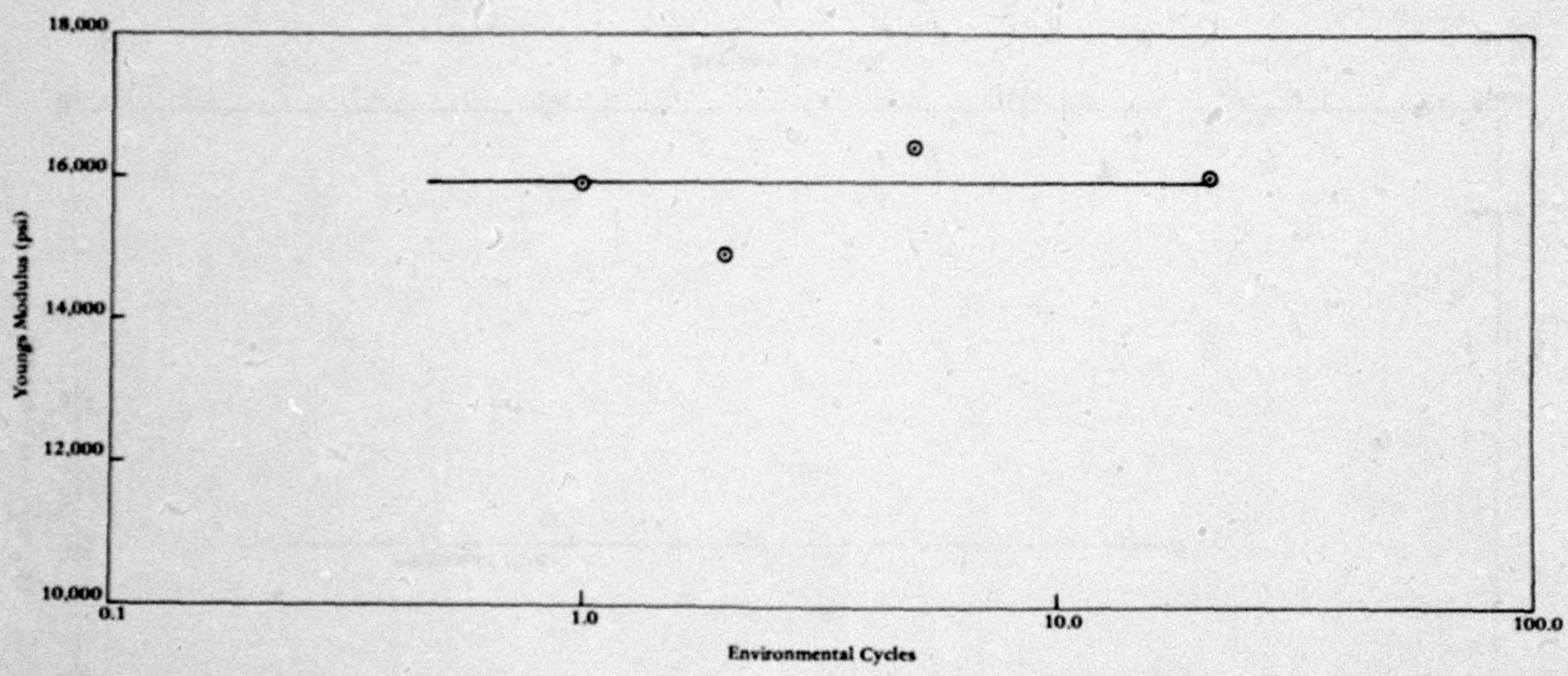


Figure 16. Effect of extreme environments on Young's Modulus, in compression parallel to rise, of unfilled CPR-739 rigid polyurethane foam (15-pcf density).

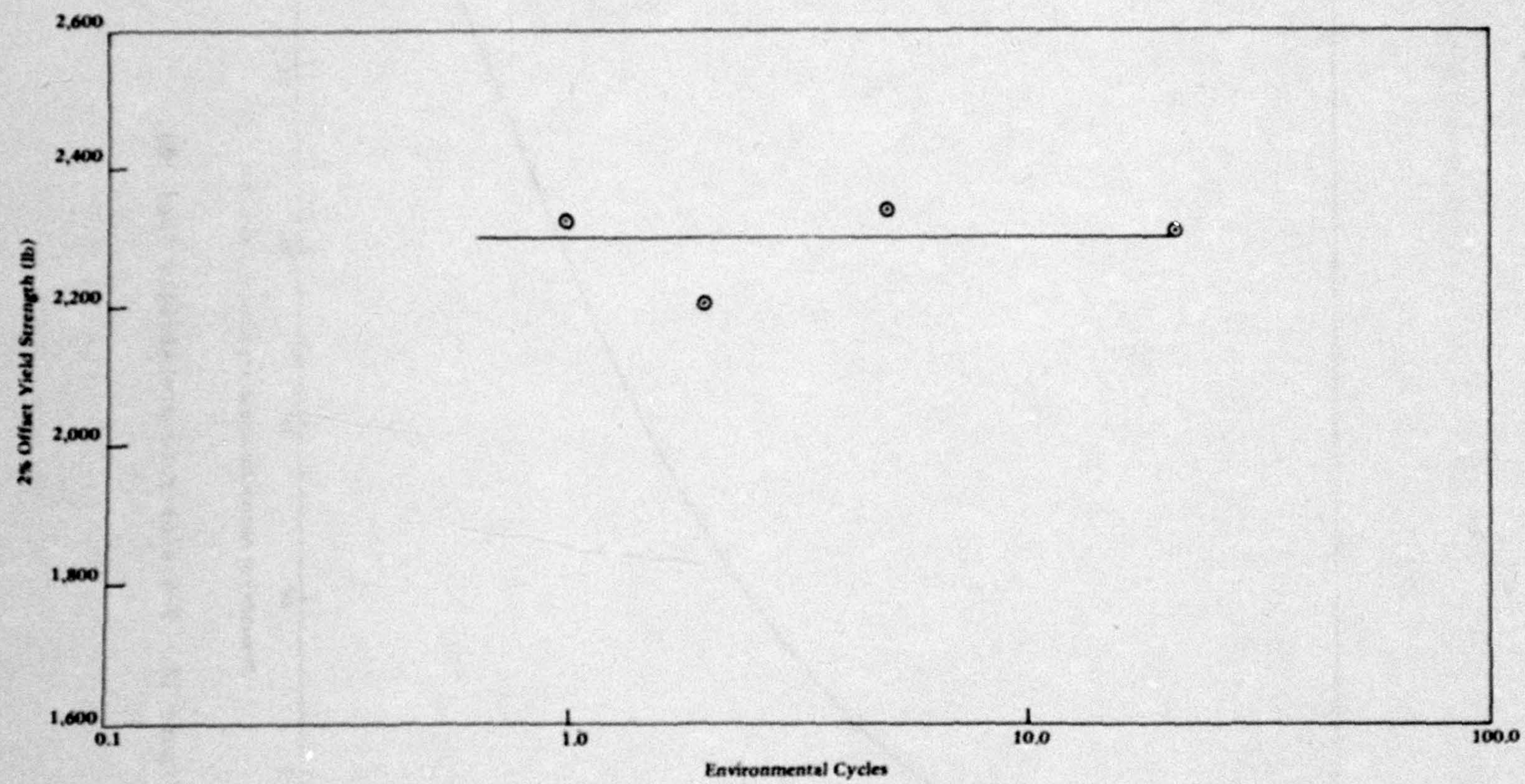


Figure 17. Effect of extreme environments on compressive yield strength of unfilled CPR-739 rigid polyurethane foam (15-pcf density).

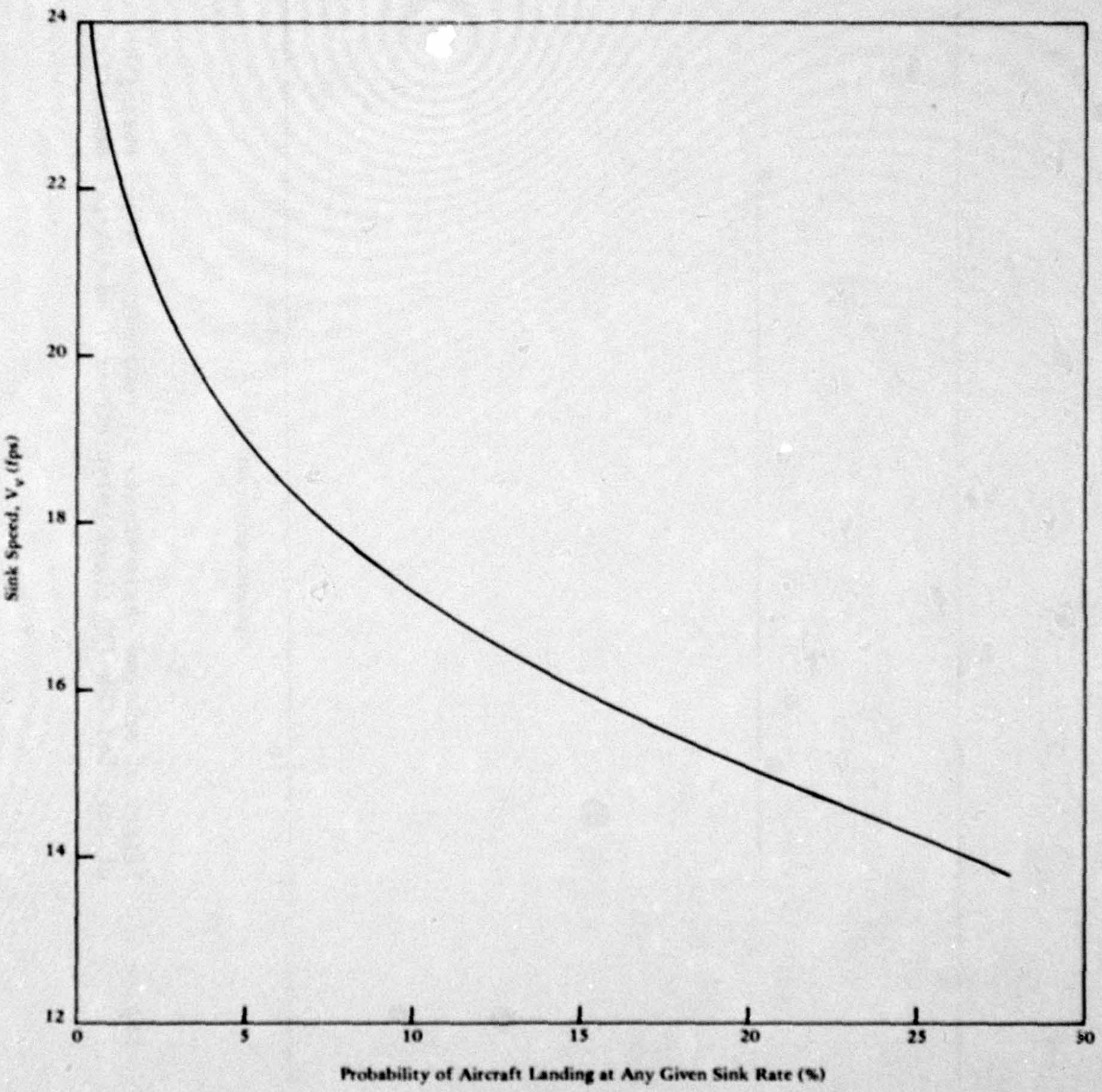


Figure 18. F-4 sink rate probability (Ref 18).

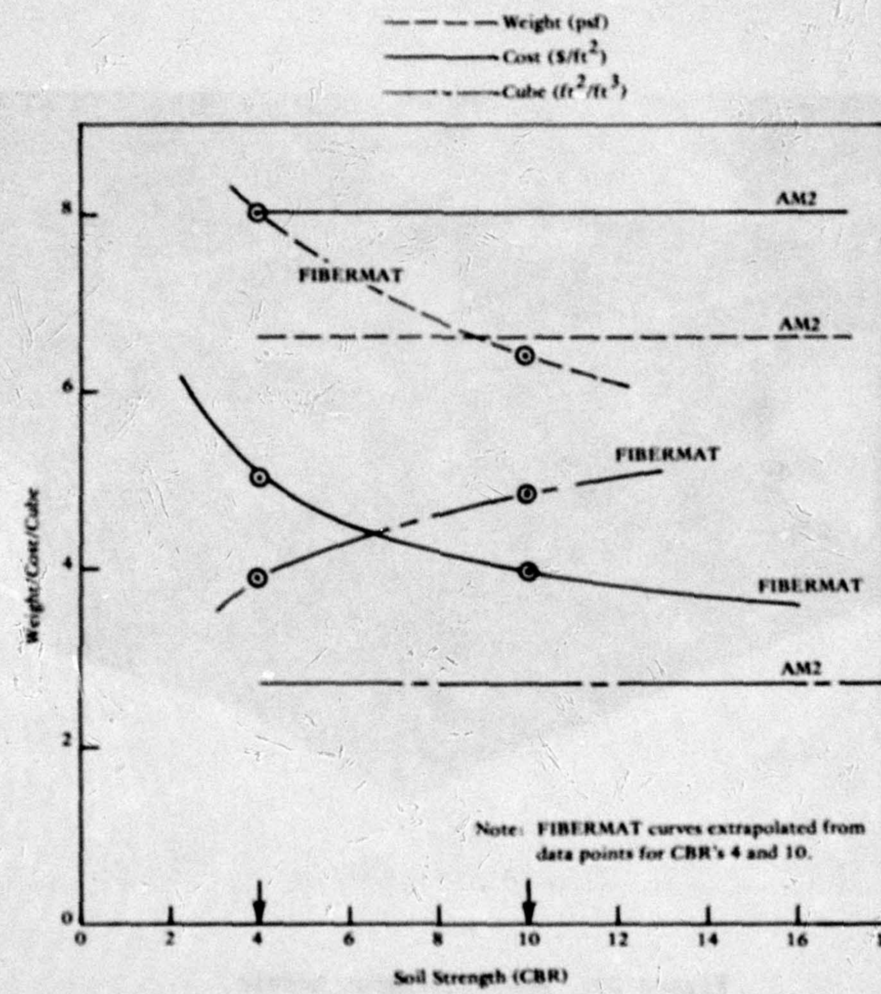


Figure 19. FIBERMAT and AM2 logistics factors.

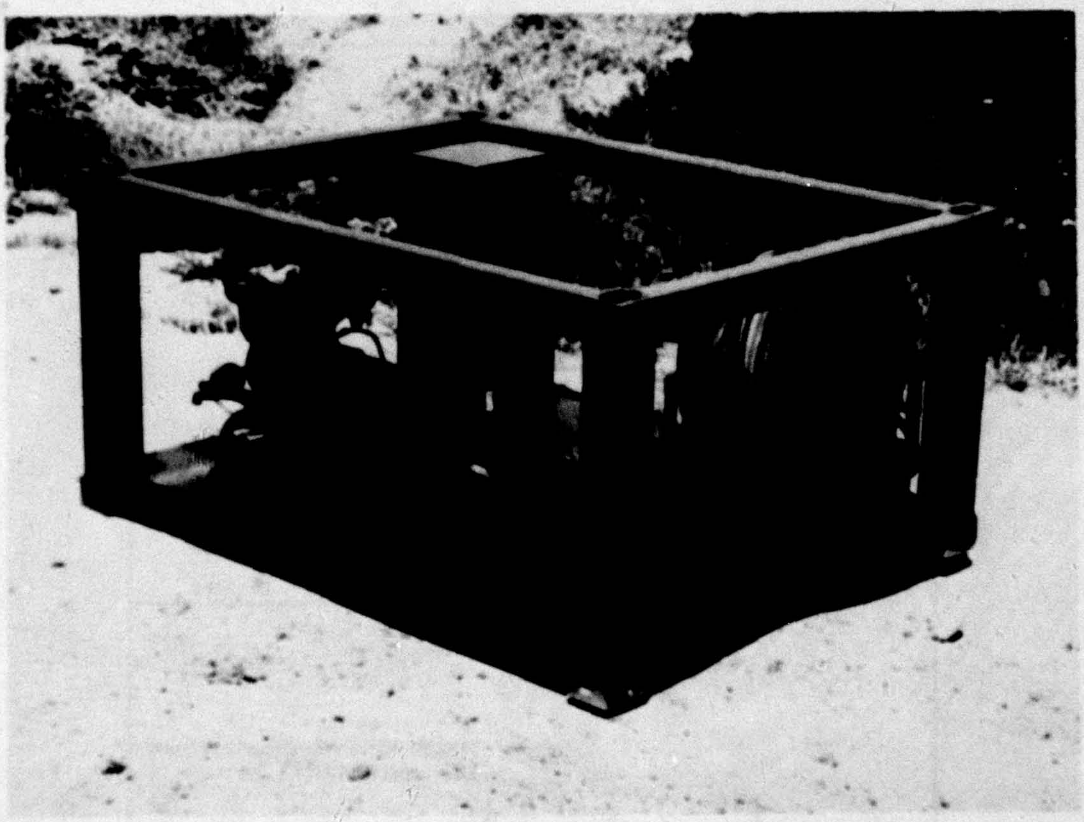


Figure 20. AMSS equipment module.

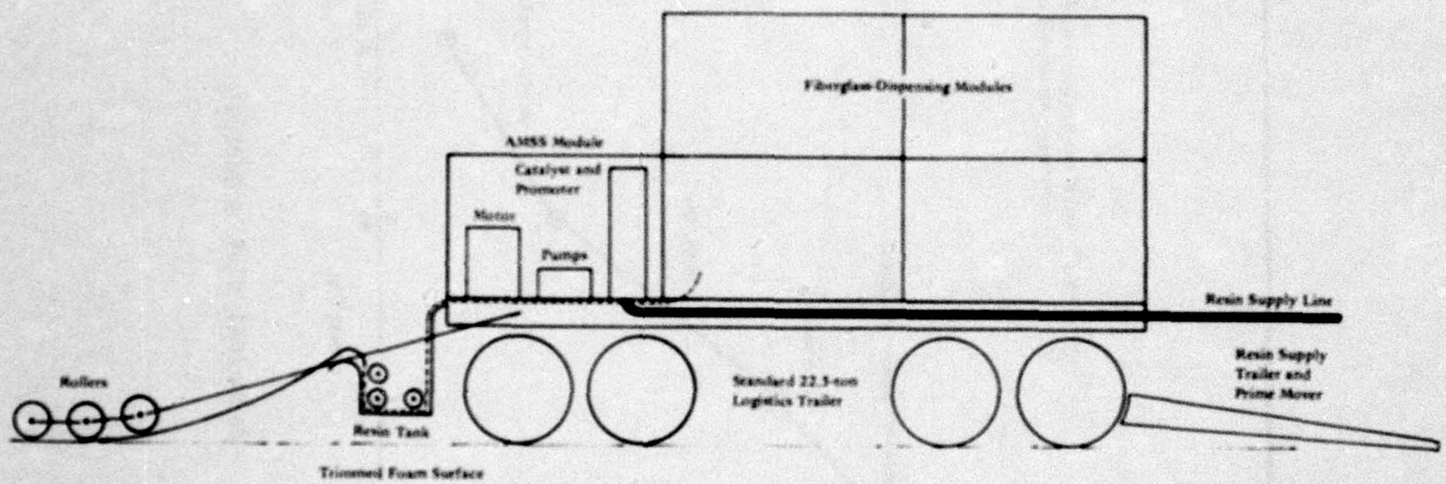


Figure 21. Laminating equipment concept.

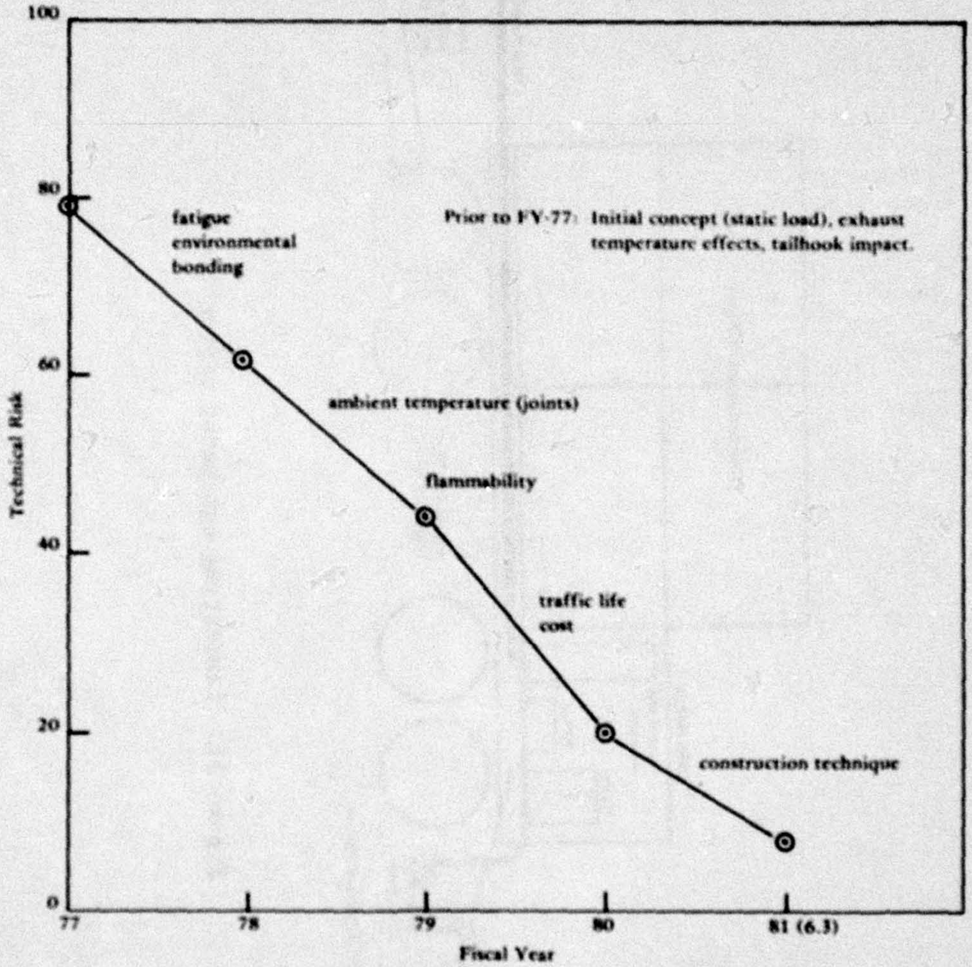


Figure 22. Technical risk reduction.

Table 1. Mechanical Properties of CPR-739 Foam (Ref 10)

[Test temperature = 74°F]

Physical Properties	ASTM Method	Values With Nominal Density[a] of --	
		20 pcf	25 pcf
Compressive Strength (parallel), psi	D1621	1,150	1,900
Compressive Modulus (parallel), psi	D1621	30,000	46,000
Tensile Strength, psi	D1623	630	820
Shear Strength, psi	C273	500	640
K Factor, Btu/ft^2-hr-°F/in.	C177	0.41	0.43

[a]ASTM method D1622 used to measure nominal density.

Table 2. CPR-739 Core Material Properties in Bending[a]

Batch	Nominal Density (pcf)	E_b (psi)	σ_b(ult) (psi)	σ_b(P.L.) (psi)	ϵ_b(ult) (μ in./in.)	ϵ_b(P.L.) (μ in./in.)	Filler Material
A2	15	14,144 ± 882	b	272 ± 11	b	19,000 ± 1,500	none
C1	15	24,127 ± 3,080	555 ± 81	368 ± 39	25,100 ± 2,100	14,800 ± 2,200	10% - 1/2-in. glass fiber
C2	15	23,035 ± 2,695	560 ± 94	504 ± 79	26,100 ± 2,300	18,900 ± 1,800	5% - 1/2-in. glass fiber
AS1	20	39,997 ± 1,801	917 ± 22	774 ± 26	23,060 ± 2,077 to > 29,376[c]	18,752 ± 390	none
CS5	20	118,871 ± 6,521	2,417 ± 82	1,684 ± 176	24,823 ± 3,231	14,100 ± 699	2% - 1-1/2-in. glass fibers plus 1 layer 2,010 woven roving/random fiber
CS1	20	72,991 ± 4,898	1,457 ± 86	1,318 ± 145	21,518 ± 617	18,470 ± 221	10% - 2-in. glass fibers

[a]ASTM Test Designation: D790-71, Flexural Properties of Plastics (Ref 13).

[b]Extreme bending without rupture.

[c]Extreme bending strain (>29,376) for four samples and rupture for two samples.

Table 3. Core Material Properties in Compression[a]

Batch	Nominal Density (pcf)	E_c (psi)	$\sigma_{c(YLD)}$[b] (psi)	$\sigma_{c(P.L.)}$ (psi)	$\epsilon_{c(P.L.)}$ (μ in./in.)	Filler
A2	16	18,306 ± 240	527 ± 7	383 ± 6	21,100 ± 500	none
C1	14	14,681 ± 613	489 ± 11	352 ± 19	24,000 ± 1,800	10% - 1/2-in. glass fibers
C2	14	17,060 ± 944	579 ± 11	403 ± 18	23,700 ± 1,700	5% - 1/2-in. glass fibers
A4	20	20,101 ± 1,428	1,096 ± 138	825 ± 106	42,500 ± 3,536	none
C12	20	25,029 ± 40	1,078 ± 24	855 ± 42	33,750 ± 1,768	2.5% - 1-in. glass fibers
D2	24	15,257 ± 632	429 ± 7		18,900 ± 1,300	15 pcf (CPR-739) and 9% sand by volume

[a]ASTM Test Designation: D1621 - 73, Compression Properties of Rigid Cellular Plastics (Ref 14).
[b]Yield strength values given for 2% deformation.

Table 4. Environmental Test Cycle (Ref 17)

Period (hr)	Temperature (°F)	Relative Humidity (%)
48	160 ± 5	<10
48	73.4 ± 2	immersed in water
8	-70 ± 5	about 100
64	100 ± 3.5	about 100

Table 5. Safety Factors for FIBERMAT Surfacing Design

Traffic Area	Factor of Safety
Runway	
Centerline (Area C)	3.0
Edges (Area A)	2.5
Impact (Area D)	1.1 (Compression) 1.5 (Bending)
Parking Apron	
Medium Duty (Area A)	2.5
Light Duty (Area B)	a

[a]To be defined by limiting soil strain.

Table 6. Design Aircraft Loads

Traffic Area	Critical Aircraft	Tire Pressure	Contact Area (in.^{2})	Load Radius (in.^{2})[a]	Rim Load[a]	
					Area (in.^{2})	Pressure (psi)
A and C - Main Runway and Medium Duty Parking Apron	F-4B	330.0	82.0	5.11	-	-
D - Main Runway (landing impact - 17 fps sink speed)	F-4B	394.0	205.0	8.08	12.5	669
B - Light Duty	C-130	95.0	467.6	12.20	-	-

[a]Superposition of stresses calculated for tire load and rim load was used to determine pavement stresses from landing impact.

Table 7. FIBERMAT Surfacing Stresses, Soil CBR of 4

Traffic Area, Section, and Load	Surface Type	Material	σ_{max} (psi)	σ_{min} (psi)	F.S.	τ_{max}	F.S.
Area C Center F-4B	FIBERMAT 0.125/4.5, 20/10	FRP Foam	342 487	-4,348 -88	3.3 3.1	2,003 288	6.0 3.0
Area A and C Shoulder F-4B	FIBERMAT 0.125/4, 20/10	FRP Foam	-341 544	-4,636 -101	3.1 2.7	2,148 323	5.6 2.6
Area D F-4B Landing Impact	FIBERMAT 0.25/5, 20/10	FRP Foam Top Foam Bottom	-1,046 -452 986	-8,299 -1,047 184	1.7 1.1 1.5	3,627 298 585	3.3 2.9 1.5
Area B C-130 CBR 10	AMSS 0.25 in.	FRP	29	-340	43	176	68

Notes:

1. Material Properties

FRP	FOAM	SOIL
$\sigma_{c(ULT)} = 14{,}500$ psi	$\sigma_{b(ULT)} = 1{,}500$ psi	CBR = 4 to 6
$E_c = 1.5 \times 10^6$ psi	$\sigma_{c(Allow)} = 1{,}150$ psi	$E_s = 6{,}000$ psi
$\tau_{ULT} = 12{,}000$ psi	$E_b = 70{,}000$ psi	$\nu = 0.45$
$\nu = 0.25$	$\tau_{ULT} = 850$ psi	
	$\nu = 0.30$	

2. Boundary conditions of SLIP computer program run: (a) free to slip tangent to boundary and (b) nodes at soil/surfacing interface locked in normal direction and unrestrained in tangent direction.

Table 8. FIBERMAT Surfacing Stresses, Soil CBR of 10

Traffic Area, Section, and Load	Surface Type	Material	σ_{max} (psi)	σ_{min} (psi)	F.S.	τ_{max}	F.S.
Area C Center F-4B	FIBERMAT 0.125/3.0, 20/10	FRP Foam	-331 441	-3,484 -187	4.2 3.6	1,576 299	7.6 2.8
Area A and C Shoulder F-4B	FIBERMAT 0.125/2.5, 20/10	FRP Foam	-323 498	-3,510 -222	4.1 3.0	1,594 360	7.5 2.4
Area D F-4B Landing Impact	FIBERMAT 0.25/3.5, 20/10	FRP Foam Top Foam Bottom	-1,113 -414 874	-6,484 -1,042 -371	2.2 1.1 1.7	2,686 314 623	4.5 2.7 1.4
Area B C-130 CBR 10	AMSS 0.25 in.	FRP	29	-340	43	176	68

Notes:

1. Material Properties

FRP	FOAM	SOIL
$\sigma_{c(ULT)} = 14,500$ psi	$\sigma_{b(ULT)} = 1,500$ psi	CBR = 10
$E_c = 1.5 \times 10^6$ psi	$\sigma_{c(Allow)} = 1,150$ psi	$E_s = 15,000$ psi
$\tau_{ULT} = 12,000$ psi	$E_b = 70,000$ psi	$v = 0.30$
$v = 0.25$	$\tau_{ULT} = 850$ psi	
	$v = 0.30$	

2. Boundary conditions of SLIP computer program run: (a) free to slip tangent to boundary and (b) nodes at soil/surfacing interface locked in normal direction and unrestrained in tangent direction.

Appendix A

BENCH MODEL FOAM MIXING EQUIPMENT

A "bench model," two component, resin dispensing system (Figure A-1) was designed and fabricated under contract with Johnson and Sons, Glendale, Calif. Using two Viking pumps, the system delivers CPR-739, 20-pcf, polyurethane foam components at an output rate of approximately 10 lb/min. The foam component characteristics are given in Table A-1. The system is air-powered and requires 36 cfm at 100 psi. Component ratios can be varied from a 2:3 ratio to a 3:2 ratio by turning an adjustment knob on a Link-Belt P.I.V. 50 variable-speed gear box, manufactured by Food Machinery Corporation.

A "static type" mixer (Figure A-2) mixes the components by splitting and recombining the materials hundreds of times as they pass through the 15-inch-long mixing chamber. Two hoses carrying the component materials from the pumps to the spray gun remain in a "wet" condition between jobs and are rinsed with solvent only prior to prolonged storage. A separate line runs from an air-pressurized (30-psi) solvent tank to the spray-gun mixing chamber to efficiently clean the mixing chamber and spray nozzles with minimal solvent usage (approximately 1 quart).

A fiberglass cutter mounted at the tip of the spray gun (Figure A-3) breaks glass fibers from continuous roving, and the fibers drop into the path of the mixed foam components as they exit the spray nozzles. The quantity of glass cut is controlled by the speed of the cutter and is varied by regulation of the air supply to the cutter; fiber length is controlled by the number of blades positioned circumferentially on the cutting head.

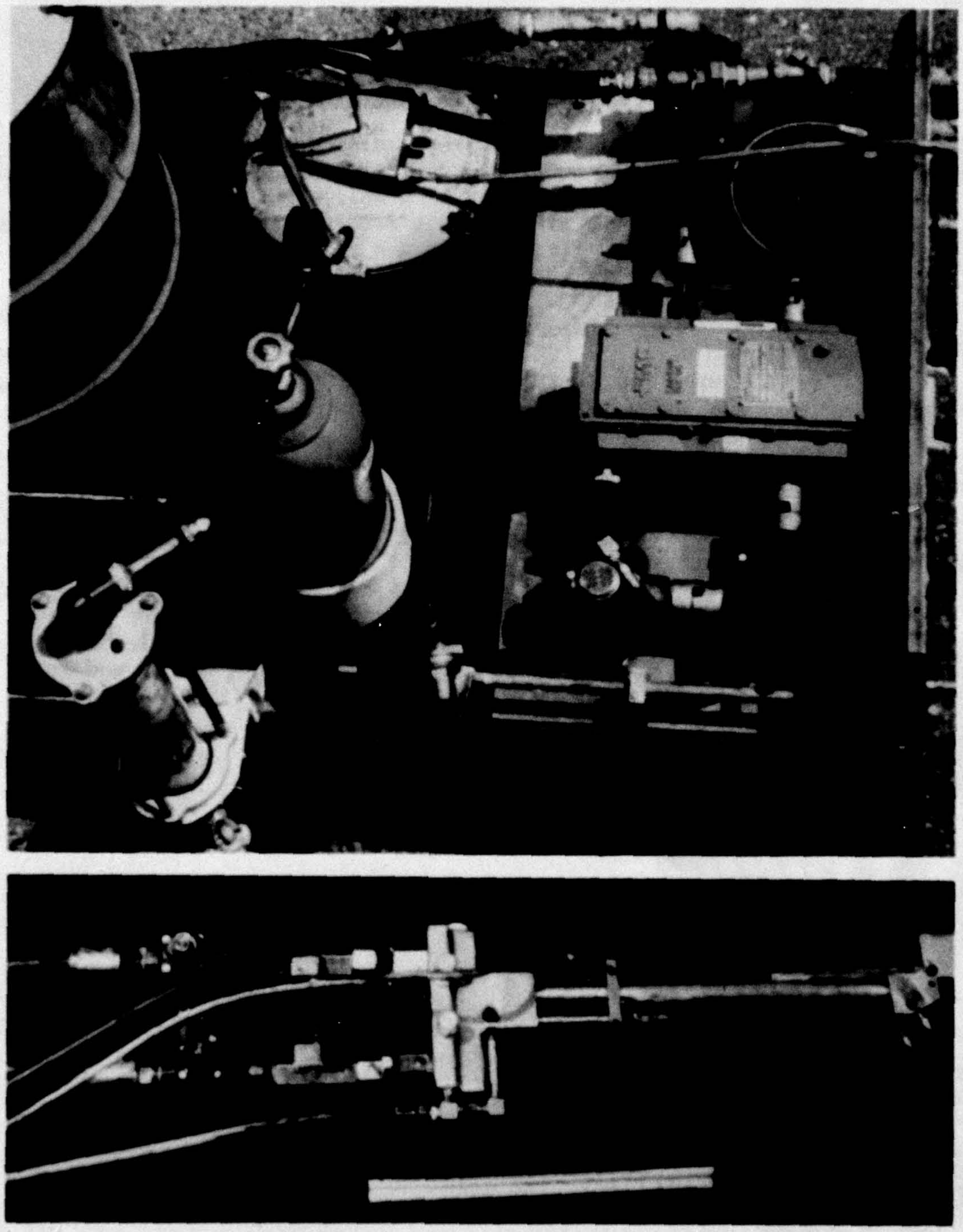


Figure A-1. Bench model two-component foam mixing/dispensing system.

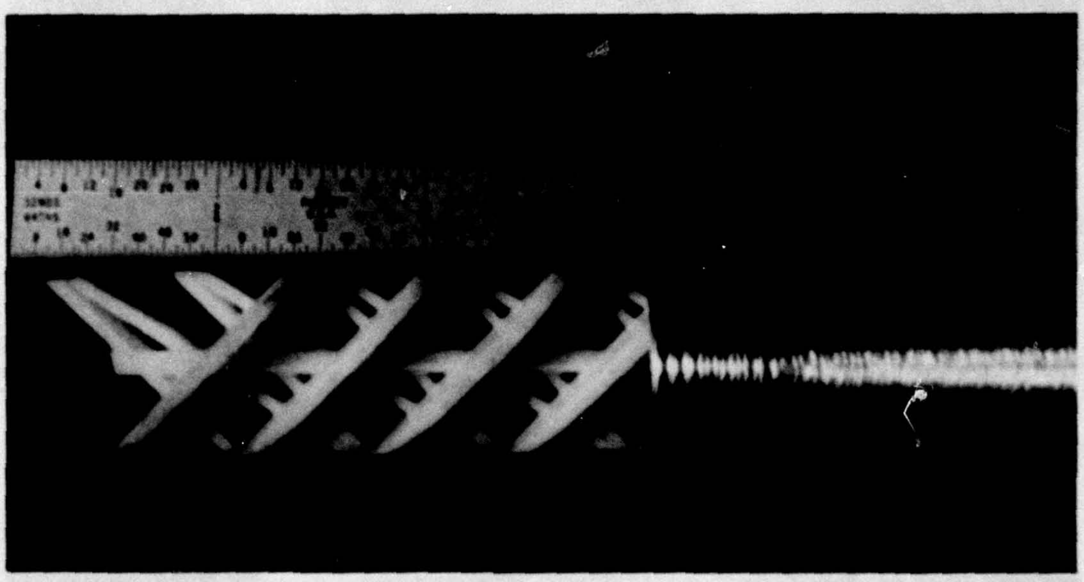


Figure A-2. Static component mixer.

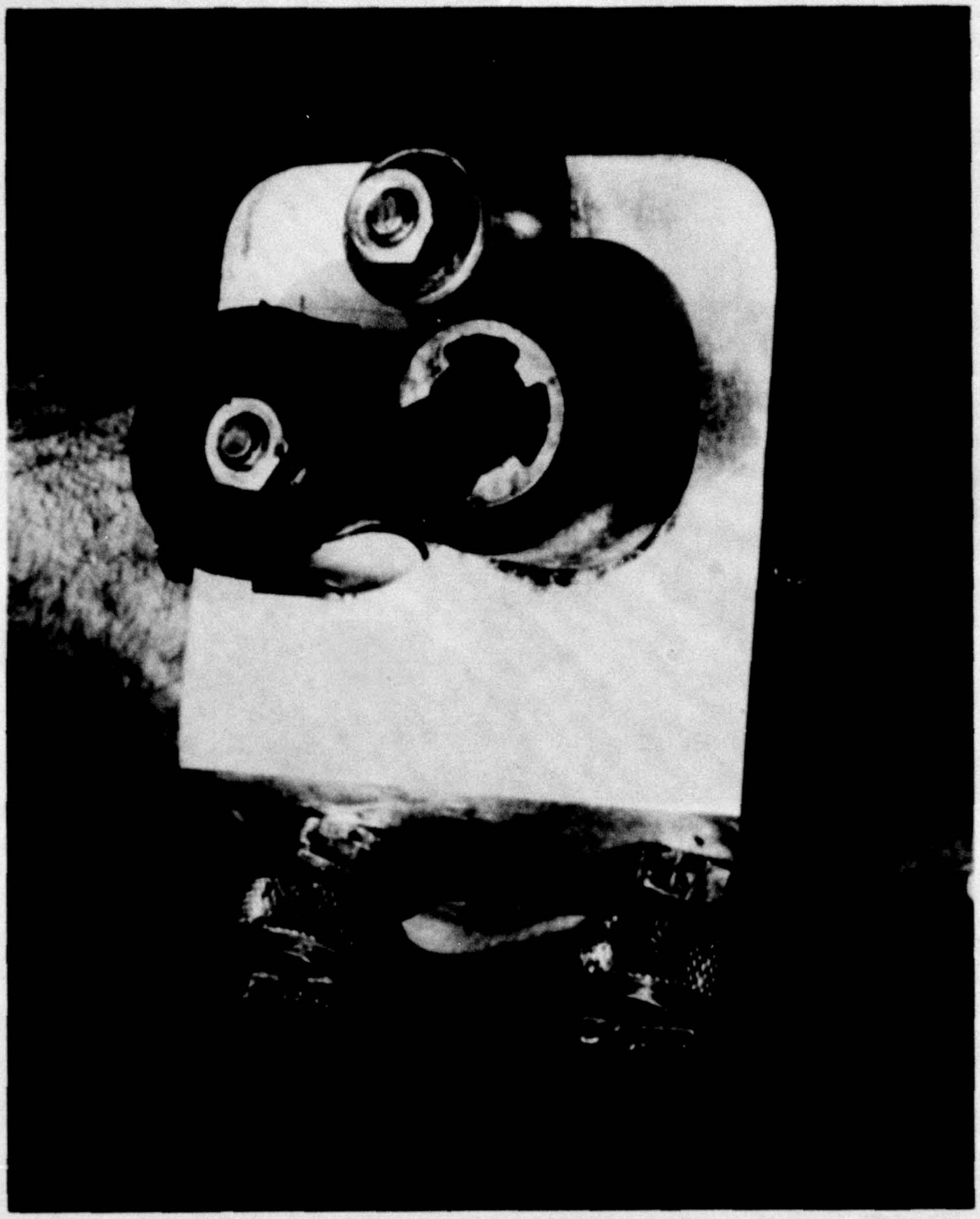


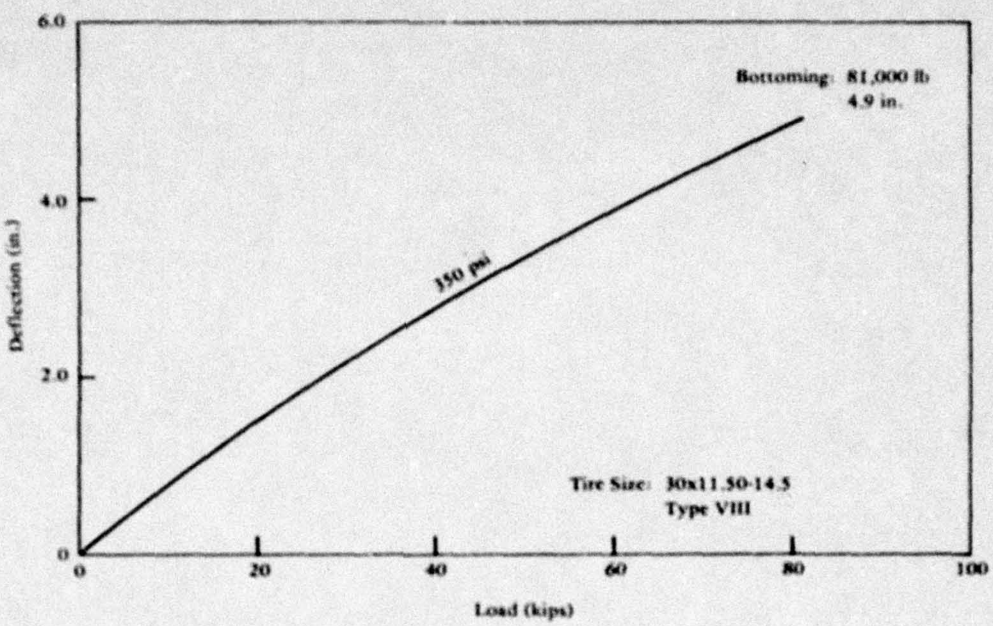
Figure A-3. Fiberglass cutter.

Table A-1. Characteristics of CPR-739/20 Polyurethane Foam Components

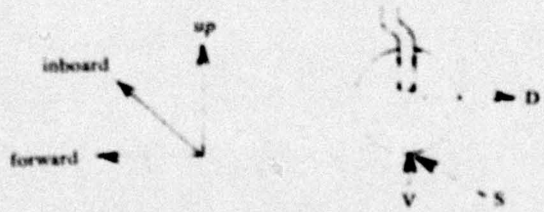
[Cream Time (75°F): 120-150 sec; Rise Time (75°F): 13 min]				
Component Chemical Name	Viscosity		Specific Gravity	Ratios for 20 pcf (parts by weight)
	cps	Temperature (°F)		
Polymeric Isocyanate/ Pryophosphate	2,600	75	1.12	56.8
	1,700	80		
	1,200	85		
	1,000	90		
Polyol Resin	3,100	75	1.24	43.2
	2,100	80		
	1,500	85		
	1,200	90		

Appendix B

AIRCRAFT LANDING GEAR AND LANDING CHARACTERISTICS



(a) Main landing gear tire load deflection diagram for F-4 (Ref 27).



Loading conditions	Tail down, maximum strut
Sink speed	23.4 fps
Pitch	14.0 deg
Roll	0.0 deg
Strut stroke from extended	13.5 in.
Deck loads	
V_g + up	123.0 kips
D_g + outboard	-9.0 kips
S_g + inboard	4.9 kips

(b) F-4 main landing gear design loads, 38,000-pound landing gross weight (Ref 27).

Figure B-1. F-4 tire and landing gear characteristics.

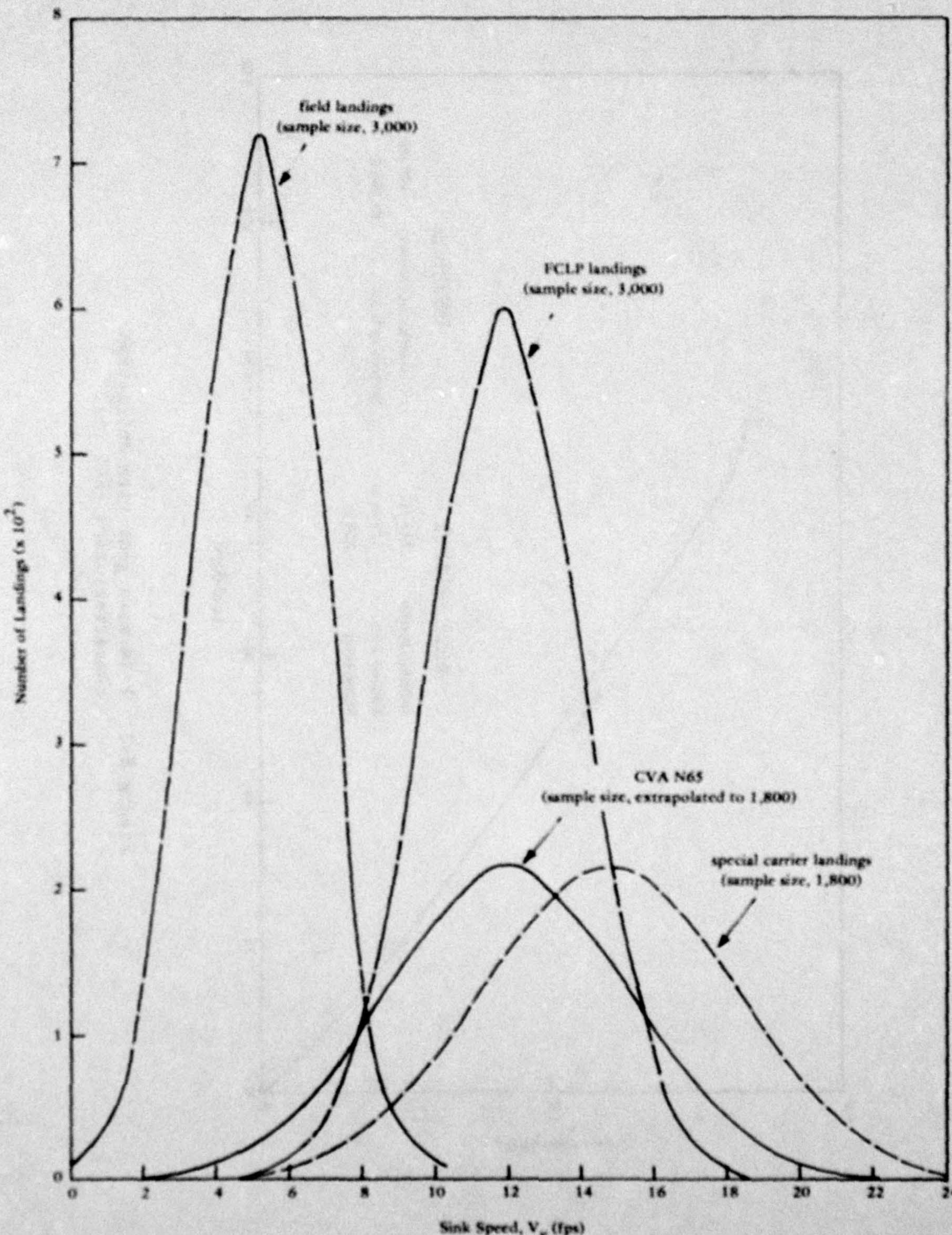


Figure B-2. Distribution of F-14 sink speeds (Ref 25).

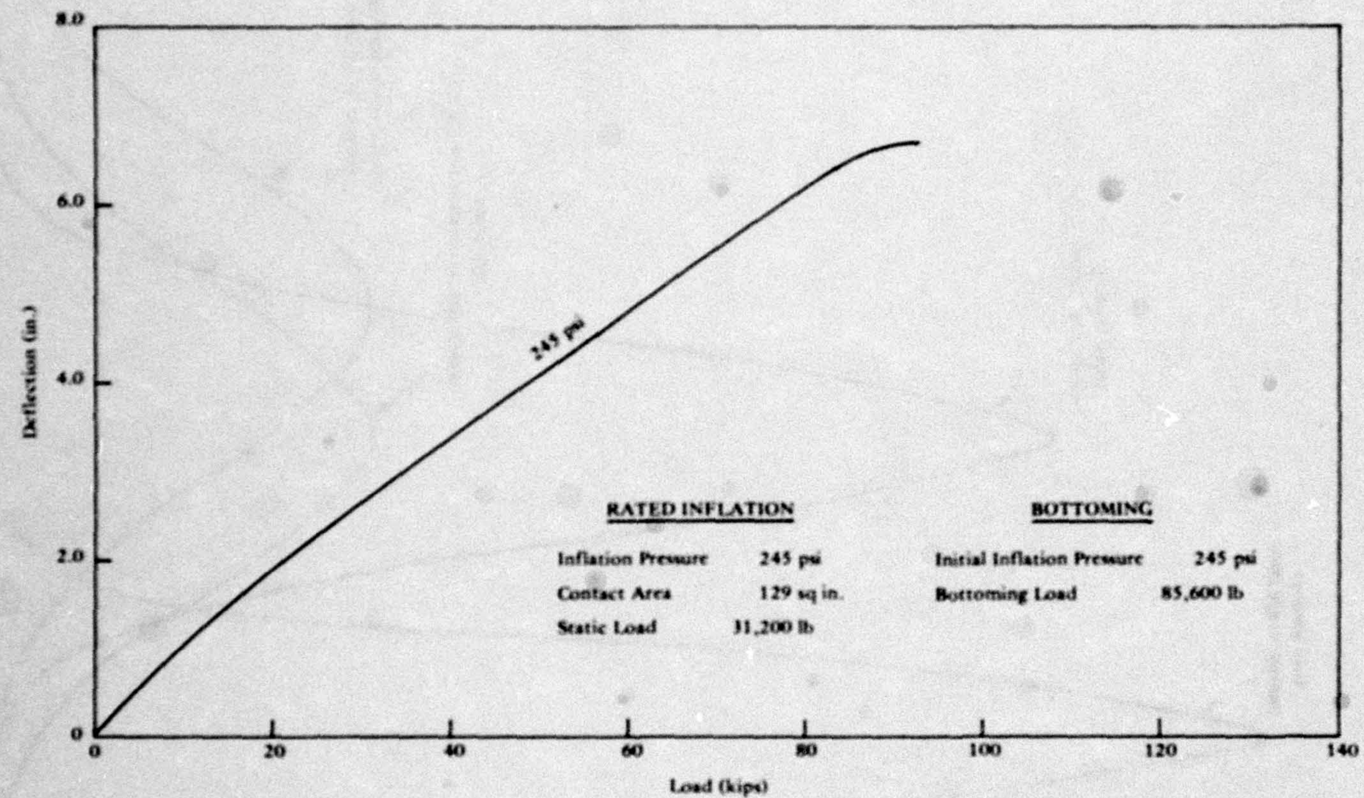


Figure B-3. F-14 main gear tire deflection characteristics (Ref 25).

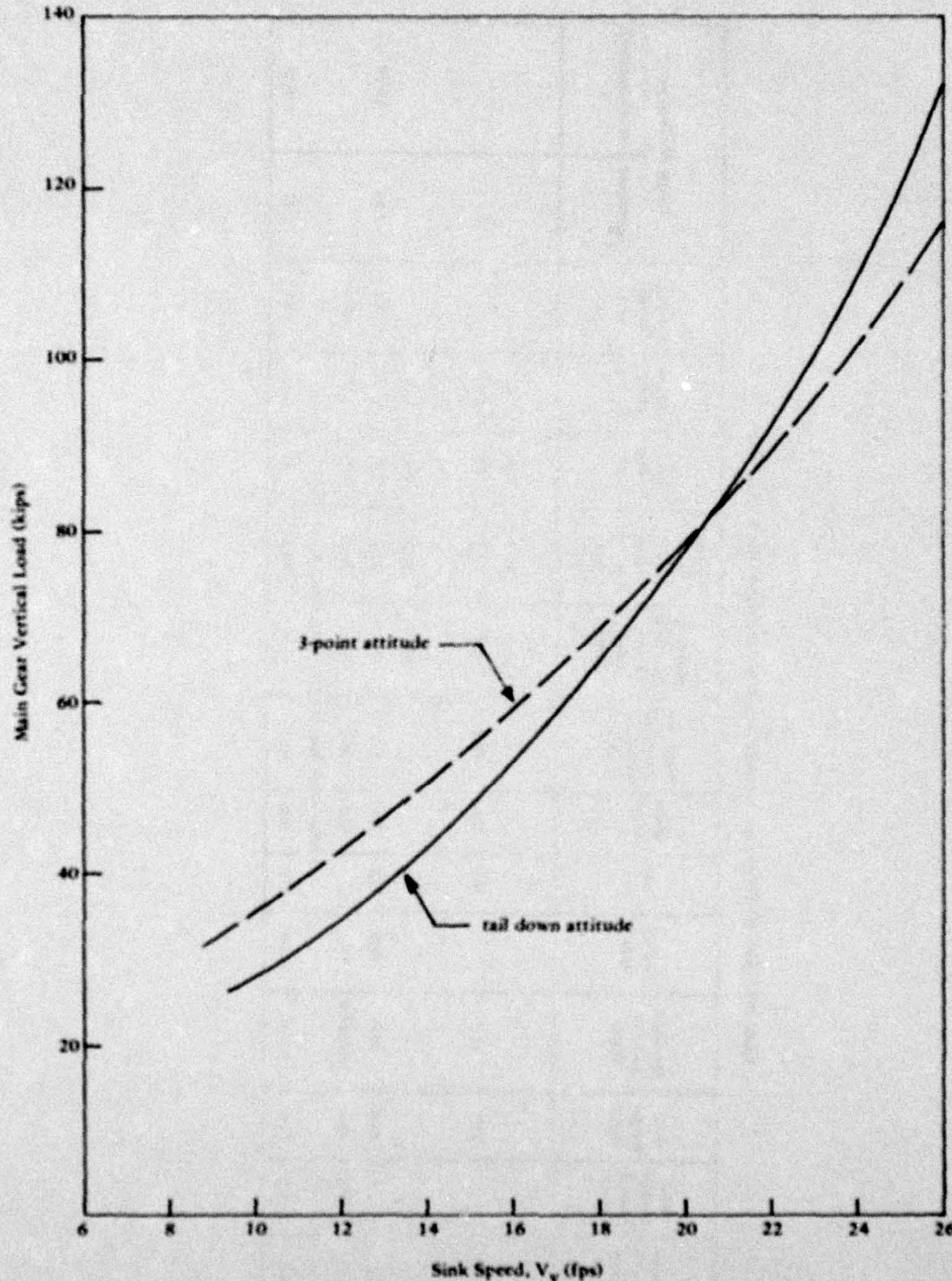


Figure B-4. F-14 main gear vertical load versus sink speed (Ref 25).

Table B-1. Aircraft Weight and Landing Gear Characteristics (Ref 5,24,25,26)

Aircraft	Maximum Takeoff (kips)	Basic Mission Takeoff (kips)	Basic Weight (kips)	Maximum Landing (kips)	Landing (kips)	Tread (in.)	Wheel Base (in.)	Maximum Weight on Main Gear (%)	Maximum Main Gear Wheel Load (kips)	Equivalent Single Wheel Load Landing-Mat (kips)	Tire Pressure (psi)	Contact Area (sq in.)	Footprint Width (in.)	Cycles Per Coverage Channelized	Cycles Per Coverage Nonchannelized
Light Duty															
A-4									12.5	12.5	200	62			
Harrier (P1127)	22.2		12.2	17.5		264	132	65.0	7.2	13.7	75	183			
Medium Duty															
A-6									28.7	28.7	200	144			
F-4J	61.7	53.8	30.6	46.0	35.9	215	279	87.7	27.0	27.0	265	102	8.9	7.36	13.38
F-14	69.8	60.0	44.0	51.8/24 fps	58		276	86.0	30.0	30.0	245	129	6.4		
F-18							Information Requested From Northrup/McDonnell								
C-130E	175.0	151.2	71.5	175.0	133.3	172	388	95.7	41.9	44.4	95	467	18.3	2.12	3.58

Appendix C

EAF MATERIAL LOGISTICS TABLES

Tables C-1 and C-2 summarize the results of calculations of material weights, volumes, cube, and cost for construction of pavement sections for traffic areas A, B, C, and D of an expeditionary airfield. The design pavement sections for EAF's constructed over two soils (of CBR 4 and 10) are given in the main text (Tables 7 and 8). Material calculations included the following allowances:

- Sufficient foam to construct each section to a +0.5-inch tolerance.
- 0.74-psf resin per layer (0.125-inch) of Fabmat 4020* fiberglass mat. Resin and fiberglass quantities adjusted by +10% to account for any waste or loss.
- Edge lapping of fiberglass mats by 12 inches.

For cube calculations, resin and fiberglass were considered as packed together in standard 8 x 8 x 20-ft containers. The resin "weights out" and the fiberglass "cubes out"; thus, an optimum container stuffing was considered as 31,000 pounds of polyester resin plus 9,072 pounds of fiberglass mat for a total payload of 40,072 pounds. Polyester resin was considered as packaged in modules within the container. The modules were estimated as filled to 83% of capacity.

*A product of Fiberglass Industries, Inc., Amsterdam, N. Y., Fabmat 4020 signifies 40 oz/sq yd woven roving plus 2 oz/sq ft random fiber.

Table C-1. EAF Logistics Summary for Soil CBR of 4

[Average Weight: 8.02 psf; Average Cost: $5.01/ft^2; Cube Ratio: 3.89 ft^2/ft^3]

Material Component	Density (lb/gal)	Logistics for Following Traffic Areas --					Number of 8x8x20-ft Containers	Volume (ft^3)	Unit Cost ($/lb) 1977	Cost ($)
		A, 555,528 sq ft (lb)	B, 354,936 sq ft (lb)	C, 64,440 sq ft (lb)	D, 253,696 sq ft (lb)	Totals (lb)				
Polyester Resin	10.2	452,199	577,836	52,455	413,017	1,495,507	48	61,440	0.68	1,016,945
Fiberglass Cloth[a]		265,689	339,504	30,819	242,666	878,676			0.80	702,941
Fiberglass Strand		104,161		13,425	58,139	175,725			0.65	114,221
Foam										
Component A	10.34	2,366,549		305,016	1,320,910	3,992,475	100	128,000	0.60	4,217,403
Component B	9.34	1,799,910		231,984	1,004,636	3,036,530	91	116,480		
Solvent[b]	≈8.3					255,735	6	7,680	0.30	76,721
Promoter	≈8.3					2,691	1	1,280	1.25	3,364
Catalyst	≈8.3					10,768	1	1,280	2.00	21,536
Totals						9,848,107	247	316,160		6,153,131

[a]Weight equals 0.4 psf/layer.

[b]Estimated at 3% solvent by weight of resin.

Table C-2. EAF Logistics Summary for Soil CBR of 10

[Average Weight: 6.39 psf; Average Cost: $4.05/ft^2; Cube Ratio: 4.85 ft^2/ft^3]

Material Component	Density (lb/gal)	Logistics for Following Traffic Areas —					Number of 8x8x20-ft Containers	Volume (ft^3)	Unit Cost ($/lb) 1977	Cost ($)
		A, 555,528 sq ft (lb)	B, 354,936 sq ft (lb)	C, 64,440 sq ft (lb)	D, 253,696 sq ft (lb)	Totals (lb)				
Polyester Resin	10.2	452,199	577,836	52,455	413,017	1,495,507	48	61,440	0.68	1,016,945
Fiberglass Cloth[a]		265,687	339,504	30,819	242,666	878,676			0.80	702,941
Fiberglass Strand		69,441		11,411	47,568	128,420			0.65	83,473
Foam										
Component A	10.34	1,577,699		259,263	1,080,744	2,917,706	73	93,440	0.60	3,082,084
Component B	9.34	1,199,940		197,186	821,975	2,219,101	70	89,600		
Solvent[b]	≈8.3					198,969	5	6,400	0.30	59,690
Promoter	≈8.3					2,692	1	1,280	1.25	3,364
Catalyst	≈8.3					10,768	1	1,280	2.00	21,536
Totals						7,851,839	198	253,440		4,970,033

[a]Weight equals 0.4 psf/layer.

[b]Estimated at 3% solvent by weight of resin.

ACRONYMS AND ABBREVIATIONS

AOA	Amphibious Objective Area
MAGTF	Marine Air/Ground Task Force
MAG	Marine Air Group
V/STOL	Vertical and Short Takeoff and Landing
IOC	Initial operating capability
SATS	Short Airfield for Tactical Support
VTOL	Vertical Takeoff and Landing
EAF	Expeditionary Airfields
FOMAT	Structural sandwich of rigid polyurethane foam between outerfacings of fiberglass-reinforced polyester
CBR	California Bearing Ratio
ESWL	Equivalent single wheel load
AMSS	Advanced Multipurpose Surfacing System
FRP	Fiberglass-reinforced polyester
SFRF	Steel-fiber-reinforced foam
FIBERMAT	Fiberglass-reinforced polyurethane foam with surface facing of FRP
SLIP	Finite element computer code for analysis of wheel load-induced pavement stresses
RIM	Reaction injection molding
ISO	International Standardization Organization
Pre-Preg	Pre-impregnated reinforcements
ASTM	American Society for Testing and Materials
VF/VA	Navy fighter/Navy attack aircraft designations

ACRONYMS AND ABBREVIATIONS
(Continued)

VMGR	Marine Aerial Refueler/Transport Squadron
PCA	Portland Cement Association
FCLP	Field Carrier Landing Practice

LIST OF SYMBOLS

D	Drag Load on Landing Gear (lb)
E_b	Young's Modulus (in Bending) (psi)
E_c	Young's Modulus (in Compression) (psi)
E_s	Young's Modulus for Soil (psi)
F.S.	Factor of Safety
P_{ULT}	Ultimate Load (lb)
S	Spin-Up Load on Landing Gear (lb)
V	Vertical Load on Landing Gear (lb)
V_v	Vertical Sink Rate (ft/sec)
ε_b	Bending Strain (in./in.)
μ	Coefficient of Friction
ν	Poisson's Ratio
σ	Normal Stress (psi)
σ_b	Normal Stress in Bending (psi)
$\sigma_{b(ULT)}$	Ultimate Normal Stress in Bending (psi)
$\sigma_{c(Allow)}$	Allowable Compressive Normal Stress (psi)
$\sigma_{c(ULT)}$	Ultimate Compressive Normal Stress (psi)
σ_{max}	Maximum Principal Normal Stress (psi)
σ_{min}	Minimum Principal Normal Stress (psi)
σ_{PL}	Normal Stress at Proportional Limit--2% Offset (psi)
τ	Shear Stress (psi)
τ_{max}	Maximum Principal Shear Stress (psi)
τ_{ULT}	Ultimate Shear Stress (psi)

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NMCB 5, Operations Dept.; 74, CO; Forty, CO; THREE, Operations Off.
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UNITED KINGDOM Cement & Concrete Assoc Wexham Springs, Slough Bucks; D. Lee, London; D. New, G. Maunsell & Partners, London
BULLOCK La Canada
ERVIN, DOUG Belmont, CA
R.F. BESIER Old Saybrook CT
CEC Parisi, Anthony M., LT